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Towards a unity of knowledge

The aphorism *tempora mutantur nos et mutamur in illis* has lost none of its truth with the passing of the centuries, but it is disturbingly evident that its lesson is not being applied today. Within the past century man's whole way of life has been changed, mainly through scientific discovery and its application, but it would be idle to assert that civilization has adequately adapted itself to the new conditions. It would, indeed, be surprising were it otherwise, so headlong has the pace of material development become, but one may nevertheless ask whether we are not being too much swept along by the technical changes of the age and making too little effort to change our ideas to accord with them.

It is argued that the deep differences which so unhappily divide the world today spring in large measure from the fact that man's moral stature has not increased in proportion to his sudden great access of material power and wealth. While this is certainly true, what seem to be moral problems often have material roots without which they would not arise. Poverty, famine, and pestilence are among great material evils which tend to find irrational outlet in oppression or violence excused as the righting of moral wrong. It would be an ill world if all standards were material, but it would be a better world if all basic material wants —food, clothing, housing, health—were satisfied. To this goal of satisfying material wants the intensive application of science seems by general consent to be our most hopeful route.

If this thesis be accepted, it follows that we require the widest and most rapid dissemination of knowledge of new scientific and technical advances, so that it can be turned to practical account with the least possible delay, and a general appreciation of both the nature and importance of science and technology. It cannot be said that the present organization for effecting this is satisfactory; far more serious, it cannot even be said that the grave dangers arising from its shortcomings are generally appreciated by those who determine policy.

How the problem is to be solved is very far from clear, but a prerequisite to any attempt is recognition of its gravity and of the fact that we must be prepared to make far-reaching changes. While the nature of the changes necessary is very controversial, not least because every country and every class has its own problems, some points seem to have gained a fair measure of acceptance.

Basically, it is agreed, the problem must be one of education, a process which in its widest sense goes on throughout life but whose main pattern has generally to be established in the early formative years. Here two opposing tendencies must be reconciled. On the one hand, the development of civilization as we know it today depends on the availability of large numbers of people having advanced technical knowledge: as economic and other factors strictly limit the number of years that can be given to formal education, a corollary of this is that each of these people must specialize at a fairly early age and thus have correspondingly little time for the study of what are broadly called the humanities. This is a most serious loss, for humanizing influences are not so abundant in the world that we can afford to diminish them. On the other hand, education based on the humanities alone is on many counts quite inappropriate to the times in which we live. In short, how can science be infused into the humanities, and the humane studies into science, without so diluting either that their savour is lost?

It does not seem that the gap is unbridgeable. Part at least of the difficulty appears to lie in the tendency to look upon science and the humanities as two quite separate entities, which may perhaps be studied side by side but yet have nothing in common. If this premise were discounted, however, and it could be accepted that the two were different parts of one vast field of learning, the consequences might be far-reaching. A century ago the immense learning represented by the humanities far exceeded that represented by science; since then the humanities have made relatively slow progress, whereas science has advanced with giant strides. A union of the two would be a formidable combination.

There is some evidence, at least, that such a synthesis need not be an idle dream. Within science itself there is occurring a process of unification that might have seemed no less difficult only a few decades ago. During the greater part of the nineteenth century science advanced along three major but apparently steadily diverging routes—physics, chemistry, and biology. Now the process of divergence has greatly diminished, and among the most fertile fields are those in which several branches of science have combined. While the specialist is more essential than ever, narrow specialization seems to be paying diminishing

dividends, although there must always be a place for the individual with a flair for it. Again, the once important distinction between pure and applied science is increasingly being seen to be an artificial one. The problems posed in the application of science need be intellectually no less challenging than those encountered in the pursuit of scientific knowledge for its own sake. The Grecian concept that practical matters were necessarily on a low intellectual plane, and unworthy of the attention of free men, can be seen in retrospect as a fatal defect, but it could equally well be the downfall of our own civilization.

That some similar unification of science with the humanities is possible seems arguable on sounder grounds than those of mere analogy. Archaeology, for example, has been infused with new life by the adoption of a wide range of scientific techniques, and now provides ground on which scientist and classic can meet on equal terms. History, which has successively extended its boundaries to include political, social, and economic history, is now extending them further to include the history of science and technology, long studied largely in isolation. Problems of philosophy and religion are increasingly engaging the attention of those primarily trained as scientists.

It would be unrealistic to suggest that such tenuous links themselves herald the opening of a new age, but they surely indicate possibilities well worth cultivating. Any unification of modern knowledge must be a tremendous and increasingly difficult task, both because of the vast amount of material to be considered and because of the many unfilled gaps. Scarcely less great would be the task of distilling from it a pattern of general education which would both reflect the unity and yet be sufficiently flexible to cater for the diverse practical needs of the nations of the world and the widely varying abilities and aspirations of individuals. But the obvious weaknesses of traditional systems, and the unbalance that results from excessive concern with purely technical subjects in education, alike urge the need for a radical revision of ideas.

Such a synthesis would have far-reaching practical, as well as cultural, effects. Although scientists form an important and influential group, there is still much prejudice against their participating in the wider fields of human affairs. Such participation is becoming increasingly necessary, and is slowly being achieved, but it is certainly not justified merely by the possession of advanced scientific knowledge. Wider knowledge and experience are essential to the scientist if he expects to be more than a technical adviser. Equally, however, the organization of science is now so complex that administrative problems have become of serious consequence, and administrative ability does not, and need not, go hand in hand with a marked talent for science. If it is to be exercised in the scientific field, however, where there is great and increasing need for it, some background of technical knowledge is clearly very desirable. This again emphasizes the need for an educational system which provides some common ground on which scientist and non-scientist can meet.

The establishment of such a common ground clearly ought to be the result of moves from both sides, but at the moment the initiative is very largely with scientists, many of whom have clearly demonstrated their ability to assist in the formulation of policy and to undertake administration at the highest levels. Unfortunately, the reverse process is still an almost completely forbidden transition, and in the present state of affairs this is understandable: policy decisions tend to be the responsibility of older men in established positions, who naturally cannot enter upon a course of scientific study detailed enough to be helpful in taking decisions relating to scientific matters. An education which included some serious study of science would, however, be a great aid to judgment.

Whether knowledge is taken to be desirable for its own sake or for the material benefits it can confer—and most people now would consider it to be desirable for both these reasons—the argument in favour of trying to effect some synthesis of science and the humanities seems to be unanswerable. From it might well stem consequences as far-reaching as those which have resulted from the recent cross-fertilization of the different branches of science, which were for so long thought necessarily committed to different paths of development.

Nuclear reactors for the generation of electrical power

SIR CHRISTOPHER HINTON

Britain is the first country in the world to have established a full-scale electrical generating station powered by nuclear energy. Three much larger stations are already under contract for the Central Electricity Authority, in addition to three dual-purpose stations under construction for the Atomic Energy Authority. This authoritative article reviews the principal factors which led to the choice of the graphite-moderated gas-cooled reactor for Calder Hall; it is predicted that under the conditions which exist in Britain and some, but not all, other countries, this type of reactor will continue to be the most suitable for electrical power stations for at least the next fifteen years. The future of more advanced types of reactors is also discussed, with special reference to the Dounreay fast reactor prototype.

The only nuclear reaction which in the light of present knowledge can be used to release heat convertible into electrical power is that in which fission takes place in one of the heavy elements at the top of the periodic table. In nature only one fissile atom exists, the isotope of uranium having an atomic mass of 235. It follows that any programme for the industrial generation of nuclear power must initially be based on the use of uranium as fuel.

When fission takes place in U^{235}, heat is released; fission products are formed which may include almost any of the elements in the middle of the periodic table; and on an average rather more than $2\frac{1}{2}$ neutrons are emitted. In order to maintain a chain reaction, at least one of these neutrons must be used to cause a further fission; the others may be absorbed either usefully or uselessly. For power generation, the amount of useless absorption must obviously be kept to a minimum, and this is done by excluding impurities which give rise to such absorption. Useful absorption must be by atoms which as a result form daughter products which can be employed in subsequent processes.

When natural uranium is used as a fuel in a nuclear reactor, the most important absorbing material present in the assembly is U^{238}. By neutron absorption this atom forms an unstable isotope which subsequently decays to form plutonium, which, like U^{235}, is fissile. The chain reaction involved in this process is shown in figure 1.

The fissile isotope exists to the extent of only 0·7 per cent in natural uranium; the remaining 99·3 per cent consists almost entirely of the non-fissile U^{238} isotope. Natural uranium can be enriched in respect of the fissile isotope by treatment in a gaseous diffusion plant, but this is an expensive process which demands the use of electrical power in very large quantities. It follows that in the initial stages of a nuclear power programme it is desirable to use natural uranium, or at any rate uranium which has been only slightly enriched in respect of the fissile isotope.

MODERATORS

The number of atoms of U^{238} which are available as targets for the neutrons released far exceeds the number of targets provided by the atoms of U^{235}, and the laws of probability would therefore determine that most of the neutrons emitted would be absorbed in atoms of U^{238} and few of them would strike atoms of U^{235} to cause further fissions. In these conditions the chain reaction would not be maintained. The probability of a neutron causing fission in an atom of U^{235} can, however, be increased, and the probability of its being absorbed in an atom of U^{238} correspondingly reduced, if the neutrons are slowed down from their initial high velocities to thermal velocities by allowing them to share their energy with other atoms before striking the atoms of uranium. The material used for thus reducing the velocity of neutrons is called a moderator, and the atoms most suitable for use as moderators are those of hydrogen, heavy hydrogen, beryllium, and graphite. Reactors in which neutrons are reduced to thermal velocities before use are called thermal reactors. The atoms of the moderator in which the uranium fuel elements are arranged in a calculated lattice can, of course, be in chemical combination with other atoms, but such atoms as are

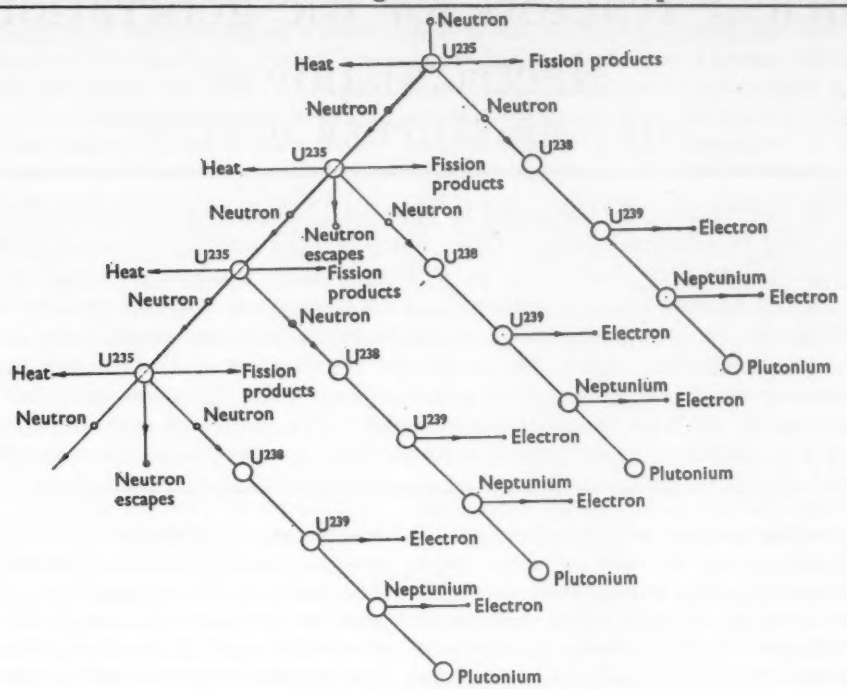

FIGURE 1 – *Chain reaction in a nuclear reactor.*

introduced in chemical combination with the moderator must not uselessly absorb neutrons.

When carbon is used as the moderating atom it is normally in the form of graphite, both because the graphitization process removes some of the impurities which it would otherwise be difficult to eliminate and because the physical and mechanical properties of graphite make it the most suitable form of carbon from the engineering point of view. Hydrogen can be used as a moderator either in combination with oxygen as water, or in the form of a hydrocarbon. Heavy hydrogen is usually used in the form of heavy water. Beryllium has generally been considered in the form of beryllium oxide.

Each of these moderators has its own advantages and disadvantages. Graphite of suitable purity is reasonably readily available, is not unduly expensive, and has fair neutron economy. It has the disadvantage that it starts to be chemically reactive with many other materials at temperatures of 500–600° C, and so imposes additional limitations on the materials which can be used in graphite-moderated reactors designed to operate at these or higher temperatures. It has the further disadvantage that it is bulky, making it difficult to construct compact graphite-moderated reactors.

Hydrogen in the form of water has the advantage of ready availability and low cost, but the disadvantage that, at the temperatures and purities which must be achieved in an atomic pile, it is highly corrosive to most materials of construction and would react rapidly with the uranium of the fuel elements if defects occurred in the protective sheath which surrounds this uranium. The use of water as a moderator has the further disadvantage that at the temperatures which must be achieved in power-producing reactors a high pressure must be used if it is to be prevented from boiling. In certain designs this would involve the use of heavy pressure shells, which would place an upper limit on the size of reacting core which could be employed. Water has too the disadvantage of a poor neutron economy, and it is not possible to design a reactor using water as a moderator which can employ natural unenriched uranium as its fuel. Some of these drawbacks can be avoided if the hydrogen is used in the form of a hydrocarbon, but in the past this has presented a difficulty in that under neutron irradiation most hydrocarbons are unstable and tend to form sludges. It should not be assumed, however, that this difficulty is insuperable.

Deuterium is normally used as a moderator in the form of heavy water, and in this form it has many of the disadvantages associated with hydrogen

when used in the form of ordinary water. It had in the past a further disadvantage that its price was very high, and it was not readily available. In recent months, however, the United States has offered to sell heavy water at prices far below those which were previously considered normal. This possibility of lower manufacturing cost considerably improves the prospects for the use of deuterium. From the point of view of neutron economy, heavy hydrogen is better than any other moderator, and this is an immense advantage.

Beryllium, used in the form of beryllium oxide, has the great attraction of high chemical and thermal stability. By using this material as a moderator it would be possible to achieve temperatures which do not appear to be within the bounds of possibility with the other moderators that have been considered. Its neutron economy is similar to that of graphite. On the other hand, beryllium is not readily available and the present cost is high.

COOLING FLUIDS

Besides the fuel element and the moderator, the remaining essential component of the core of a reactor is the coolant, and the choice of the fluid for this purpose is important in relation to the stability, and therefore the safety, of the reacting system. If in the design adopted the coolant is more effective as a neutron absorber than it is as a moderator, then the reactor may have an inherent instability. Consider, for instance, a reactor using graphite as a moderator and water as a coolant, and assume that the fuel elements are in the form of natural uranium rods lying in a tube through which the water flows. To some extent this water acts as a moderator, but its more important effect in determining the nuclear physical characteristics of the reacting core lies in the fact that it absorbs neutrons. If as a result of mechanical or electrical failure the flow of cooling water were stopped, the heat emitted from the fuel elements would be great enough to vaporize the water in the cooling annulus, and this water would be ejected from the tubes as steam. Far fewer atoms of water would then surround the fuel elements than in the normal working condition, and there would therefore be less absorption of neutrons in this water annulus. Unless the mechanically operated safety devices on the reactor worked instantaneously, the neutrons which were previously absorbed in the coolant would become available to cause further fissions. The activity of the pile might in these circumstances increase to the point where the core melted and collapsed. Avoidance of this instability is a major question in the choice of coolant and in reactor design. Apart from this important limitation, any gaseous or liquid coolant can be chosen, provided it is not a heavy neutron absorber and that its chemical and physical properties are suitable.

Gaseous coolants, in general, have a small neutron absorption cross-section and the advantage that they do not give rise to instability of the type just discussed. It is also possible to choose gases having other characteristics which make them suitable for use in a reactor. All gases, however, have the disadvantage of low heat capacity, and the power required for circulating them is therefore considerable. Of the possible gases, carbon dioxide is cheap, has reasonable stability, and is not particularly corrosive. Helium is completely inert, and this removes many of the metallurgical problems of design: it is, however, expensive and, from the British point of view, has the serious disadvantage that large supplies are available only from America. From the point of view of physical properties hydrogen is ideal, as it has very much better heat-transfer properties than either helium or carbon dioxide, but the use of hydrogen in high-temperature nuclear reactors introduces very serious metallurgical problems.

Liquid coolants have very much better heat-transfer characteristics than gases, and with them it is therefore possible to achieve considerable economies in the power required for circulating the coolant. It is also possible to achieve very much higher ratings, i.e. heat output per unit mass of fuel in the reacting core, when liquid coolants are used.

The liquid coolants most obviously suitable are water or heavy water, hydrocarbons, or liquid metals. Apart from the question of reactor stability, the use of water as a coolant has the technological disadvantages that were mentioned in connection with its use as a moderator. Hydrocarbons suffer from chemical instability under neutron irradiation. Among the metals, sodium and bismuth have a low neutron absorption cross-section and low melting points and appear to be the best coolants of this type.

It will therefore be seen that in making our selection of the best type of thermal reactor we have an embarrassing number of alternatives, since, in theory, any one of the possible moderators may be used in conjunction with any one of the possible coolants.

THE GRAPHITE-MODERATED GAS-COOLED REACTOR

In the light of these considerations it was, however, fairly easy to make the graphite-moderated gas-cooled reactor our choice for the first stages of the British Atomic Energy Programme. Neither heavy water nor beryllium was available as a moderator. When light water is used as a moderator the fuel elements must be of enriched uranium, and when our first reactors were built this was not available. Graphite could be obtained in suitable quality and quantity, and its neutron economy was such that it could be used with fuel elements made of natural uranium.

The reactors which had been built in America during the war for plutonium production had used graphite as moderator with water as coolant. It has already been pointed out that reactors built on this system are inherently unstable, and for this reason very large safety distances were adopted in choosing the location for the American installation. Such remote sites could not conveniently be found in Great Britain, and in spite of the fact that the rating that could be achieved would be lower and the design demanded higher capital stocks of uranium, it was decided to use air cooling on the initial Windscale piles. When these were built, the problem of removing the heat at a sufficiently high temperature for it to be used for power generation could not be solved sufficiently quickly, and the Windscale reactors built to produce plutonium for defence purposes were cooled simply by blowing air at atmospheric pressure over the fuel elements and wasting the heat to the atmosphere.

When, in the early 1950's, it was possible to consider the construction of reactors in which the heat of fission could be used for the generation of electrical power, it was found that the same major considerations still outweighed all others. Metallurgical research and operating experience with the Windscale reactors had made it possible to extract the heat at temperatures high enough to enable useful power to be generated through the medium of a steam cycle. Although enriched uranium was by then being produced in considerable quantities at the Capenhurst factory, this material was required for defence purposes and only limited quantities were available for research and for the industrial programme. It was therefore necessary to select a reactor which could use natural uranium as its fuel: the use of water as a moderator was thereby excluded. Neither heavy water nor beryllium was available, and so graphite was the obvious material to choose as the moderator.

It was realized that in building a reactor which could be used industrially it was necessary to adopt a system for which inherent stability could be claimed, and this could most readily be achieved by using a gaseous coolant. It should be noted that by this time it had been realized that a stable system could be built using graphite as a moderator and water as a coolant, provided that the quantity of water in the cooling annulus was increased sufficiently to ensure that the water's effect as a moderator was as great as its effect as an absorber in the neutron balance of the pile. This additional quantity of water, however, could be introduced into the cooling annulus only if enriched uranium were used in the fuel elements, and, as already pointed out, this material was not available. Moreover, the use of water as a coolant would have introduced the metallurgical problems, already mentioned, of corrosion of the tubes and possible attack on the fuel elements.

Use of liquid metals as the coolant would also have demanded enrichment of the fuel elements, and at the time of which we are speaking the technology of the use of liquid metals was still presenting very considerable problems. It was, therefore, decided that the first British power-producing reactors should be built on the graphite-moderated gas-cooled system. Helium, with its advantages of complete chemical stability, was not available. Hydrogen presented problems arising from its reactivity with the materials of construction. Carbon dioxide, on the other hand, was cheap and sufficiently non-reactive at the temperatures under consideration to be completely suitable.

The Calder Hall reactors have been fully described elsewhere[1]: their general design and appearance are shown in figures 2 and 7. The fuel elements consist of rods of uranium 1·15 inches in diameter enclosed in protective cans made of magnesium alloy and fitted with fins to increase their heat-transfer coefficient. These fuel elements stand in vertical channels within the mass of graphite moderator. In order to improve the cooling capacity of the carbon dioxide and reduce the amount of power required for circulation, the whole system is put under a pressure of 7 atmospheres. To achieve this it is necessary to enclose the whole of the reacting core in a steel vessel 37½ feet in diameter and 70 feet long, the thickness of the walls being 2 inches. The gas is circulated

[1] See, for example, JAY, K. 'Calder Hall,' Methuen, London. 1956.

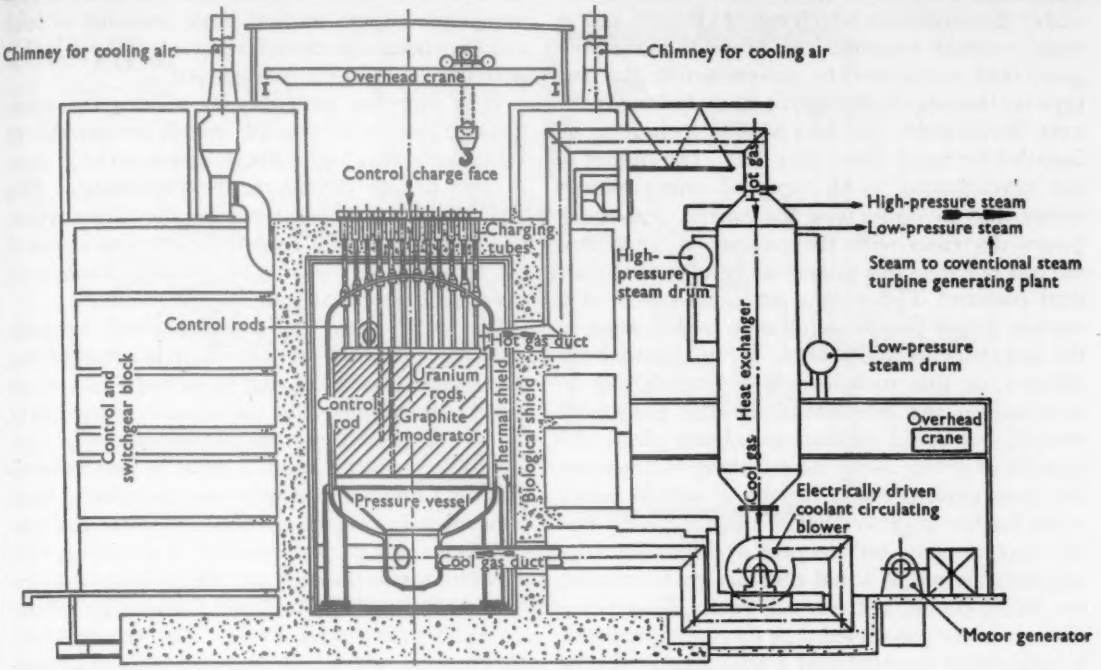

FIGURE 2 – *Diagram of the Calder Hall reactor.*

by four electrically driven blowers. It leaves the reactor at a temperature of 336° C and is passed over tubes whose heat-transfer surfaces have been increased by studs, resistance-welded on to them, giving up its heat through this transfer surface to water circulated within the tubes. Steam is raised at pressures of 200 lb per square inch and 53 lb per square inch, and is used in a dual-pressure feed in a conventional type of turbine to generate electrical power.

The Calder Hall type of reactor has the advantages that it is inherently stable; that its operation involves no greater risks than those that are normally associated with the operation of most conventional chemical plants; that it uses as its fuel natural uranium, which is widely available; and that its construction demands only materials and techniques which are well established. The reactors of this type which are at present being designed for use by the Electricity Authorities in Britain are able to generate power at a cost per unit approximately equal to the cost of power generated in a modern conventional power plant. The graphite-moderated gas-cooled reactor is the only system for which these claims can at present be made.

The system is obviously capable of very considerable improvement, and such improvements will be made in new designs as operating experience becomes greater and as research paves the way. Improvements in welding and in industrial radiography will enable pressure shells of greater thickness to be fabricated. This will give the designer the choice between increasing the diameter of the reacting core, and thus pushing up the output of the system with consequent reduction in capital cost per unit of power, or alternatively of increasing the pressure of the circulating gas, and so achieving lower power absorption in the gas circulators, smaller temperature differences between the fuel elements and the gas stream, or higher ratings of the fuel elements.

Research on the metallurgy of uranium, uranium alloys, and canning materials, and on the stability of graphite, will enable higher temperatures to be achieved with better thermal efficiencies in the steam cycle. It is possible, too, that the difficulties of using hydrogen as a coolant will be overcome. These difficulties lie in the main in the probable hydrogen embrittlement of the steel parts of the pressurized gas system and in the reactivity of hydrogen with the uranium of the fuel elements. If these difficulties can be overcome, the use of hydrogen will lead to considerably higher ratings, with very much smaller power consumption in the circulating system.

With these improvements, it is probable that

under the conditions which exist in Britain and in some overseas countries the graphite-moderated gas-cooled reactor will be pre-eminently the best type for the large land-based power station for the next fifteen years and that it will continue to be installed for many years after that. The history of the development of all types of prime movers shows that in every type the weight per horse-power decreases with the passage of time, and nuclear power plants will certainly follow this classical pattern. The weight per horse-power of a nuclear power plant can fall only as the rating of the fuel elements is increased. It has already been pointed out that such increases of rating will be achieved in the graphite-moderated gas-cooled reactor, but liquid coolants are always physically capable of giving better heat-transfer characteristics than gaseous ones. Beyond a certain point, when further improvement of the gas-cooled system becomes slow and the present difficulties arising from the use of liquid coolants are overcome, the liquid-cooled reactor will gradually replace reactors of the gas-cooled type for many purposes. It is therefore essential that a well conceived programme for the development of nuclear power should direct attention to the design of reactors which are capable of these higher ratings.

HIGH-RATING REACTORS

Besides the fact that the history of prime movers points in this direction, there is an additional factor which points to the need for development in this way. Reactors using natural uranium as a fuel and producing electricity as their primary product, produce plutonium as a by-product. This plutonium, which can be extracted from the irradiated fuel elements by chemical processes that are now well established, is available as a nuclear fuel. It is a fissile material: it is inconceivable that unlimited quantities will be required for defence purposes, and it will therefore be available for use in the industrial programme. Many difficulties lie in the way of using plutonium as a fuel, but where such a material and the theoretical possibility of its use exist, methods of solving the difficulties will unquestionably be found. When extracted from the irradiated fuel elements, the plutonium will be available as a pure fissile material. To dilute such a pure fissile material down to the point where it could be used in a reactor of low rating would appear to be unsound from both a theoretical and a practical point of view. In order to get the best returns from such a material it ought to be used in a reactor which is capable of very high ratings, so that large amounts of heat can be extracted from each kilogram of the valuable undiluted fuel which is employed.

It is therefore necessary to select some other types of reactor or reactors which are capable of being worked at high ratings, and to include these in the British development programme. This choice is by no means as easy as the choice which had to be made of a reactor for the first stages of the programme, when the graphite-moderated gas-cooled system almost selected itself.

For use in large land-based reactors we must still accept the fact that beryllium is not available in sufficient quantities, and so we must rule out its use as a moderator. The use of heavy water has in the past appeared unattractive because of its high cost. On the other hand, it must be remembered that the Canadian research team has always been disposed to favour the use of heavy water reactors, and they are at present engaged in designing such a reactor for installation on land belonging to the Ontario Hydro Electric Power Commission, about ten miles from Chalk River. The system which they propose uses heavy water as both moderator and coolant, the heat being transferred from the coolant circuit to a secondary light water cooling circuit from which steam is generated for use in the turbines. The system has all the metallurgical difficulties inherent in the use of very pure water at high temperatures and pressures, and one wonders whether under these conditions it would be possible to operate without loss of heavy water from the system. The Canadians, however, have great experience of using heavy water in reactor systems and appear to be confident on this point. The possibility of obtaining heavy water at far lower prices than were formerly assumed to be reasonable is in favour of their scheme. Figure 3 shows the schematic arrangement of the proposed reactor.

Nuclear physical stability of the core can be achieved either in a heavy water or a light water system if the moderator and the coolant are identical. In our consideration of the problem we felt that it would be preferable to use light water and to compensate for its poorer neutron economy by the use of enriched fuel elements. In a future system, this enrichment might be obtained by the use of by-product plutonium from the stage 1 reactors. The choice between these two systems is largely one of deciding whether it is better to invest in an expensive moderator and coolant, or to use a cheap moderator and coolant and invest in an expensive fuel.

Several studies have been carried out on the

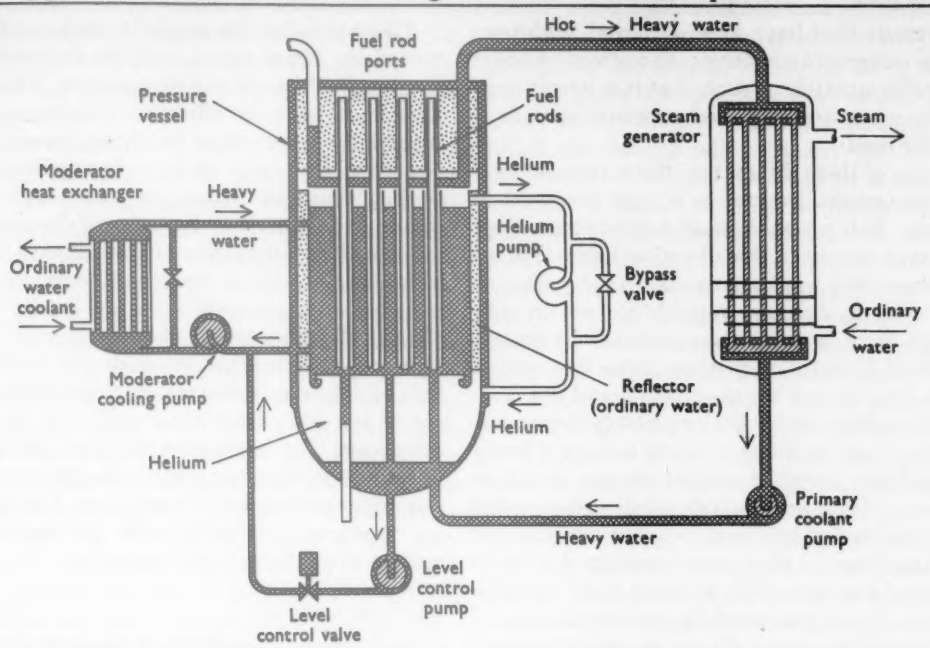

FIGURE 3 – *Proposed design for a reactor using heavy water as moderator and coolant.* (*By courtesy of Atomic Energy of Canada Limited.*)

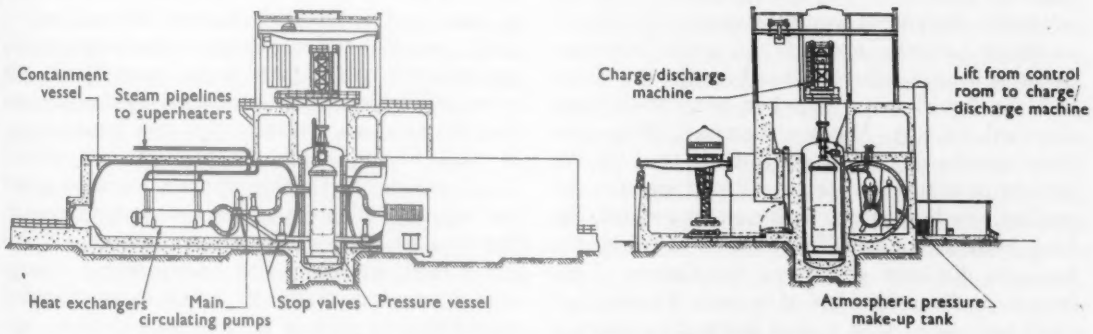

FIGURE 4 – *Tentative scheme for a reactor moderated and cooled by light water.*

feasibility of reactors both moderated and cooled by light water, and a possible scheme evolved in the course of these is shown in figure 4. It appears that if such a reactor could be successfully built and operated, the cost of generating electricity from it would be rather higher than the cost expected from the graphite-moderated gas-cooled reactors at present being designed. This, however, should not be too great a discouragement, because the system is capable of development to very high ratings, and costs must always be expected to fall as design experience is obtained. The disadvantage of the scheme shown, and of all other schemes which can at present be envisaged, is that it appears to be necessary to put the moderator under a pressure of about 1500 lb per square inch. This demands the use of a thick pressure vessel, and practical problems in the fabrication of such vessels place a limit on the size of the reactor that can be built. It does not appear that any amount of future development work can remove this limitation. It is possible that the difficulty may be alleviated by evolving a system in which the water of the moderator is allowed to boil, and this possibility is being studied. There remains, however, the disadvantage that the water used in the moderator must be extremely pure and that under the conditions of temperature

and pressure that have to be achieved, such pure water is extremely corrosive. The attack of water on metallic uranium is such that it is hardly suitable for water reactors, and uranium dioxide is generally used.

In spite of these difficulties, the water-moderated, water-cooled reactor is a type favoured in America. It is probable that American development work moved in this direction because at an early stage they expended considerable effort to evolve a reactor system suitable for use in submarines. Such an application demanded a reactor capable of higher ratings than those that can at present be achieved by gas cooling, and the difficulty of working under the completely dry conditions that must be achieved when sodium is being used probably weighed against the use of this as a coolant. Their water-moderated, water-cooled submarine reactor has been in operation for some time, and from it they have developed a large land-based reactor which is being built at Shippingport. Their published figures for the cost of power from this reactor do not at present appear as promising as those for the gas-cooled reactors.

The use of liquid metals as coolants with either water or heavy water as a moderator is very unattractive, because it would be extremely difficult to design a system in which one could guarantee freedom from a failure which brought the water and the liquid metal together, with consequent chemical reaction. We are, therefore, left to consider systems in which graphite is used as the moderator and either water or liquid metal as the coolant. Such a system, with a water coolant, has been built in Russia. The reactor, of which the Russians disclosed details at the Geneva Conference on Peaceful Uses of Atomic Energy, is a small prototype, with a total thermal capacity of 30 MW, in which the fuel elements are arranged vertically in stainless steel tubes which run through the graphite moderator. Whether nuclear stability has been achieved by proportioning the thickness of the water annulus is not clear, but apart from this, the reactor appears to be conservatively designed, and, as is reasonable in a prototype, economy seems to have been made subservient to reliability. An inherent disadvantage of this design is that the stainless steel pressure tubes within the core must be of appreciable thickness, and so impair the neutron economy. It seems a little questionable whether the design can be developed in such a way as to enable power to be produced on a large scale at costs which would be competitive under British conditions.

There remains the graphite-moderated reactor cooled by liquid metal, and for this, sodium appears to be the most suitable coolant. This reactor appears to have the objection of inherent nuclear instability, but it must be remembered that the condition in which sodium is vaporized in the cooling passages within the core ought not to occur. It follows, therefore, that if the mechanical construction of the reactor is such that in the event of failure the sodium circuit will empty itself into the core, nuclear stability ought to be ensured. Like all the other systems for highly rated reactors that we have considered, with the exception of that which uses heavy water, this system will demand the use of enriched fuels, but it has the advantage that because of the high boiling point of sodium the cooling system does not need to be put under an appreciable pressure. The engineering problems connected with the use of liquid sodium are now well understood.

FAST REACTORS

Hitherto our consideration has been confined to thermal reactors, i.e. reactors in which it is necessary to arrange a lattice of fuel within a moderator in order to maintain our chain reaction. If instead of using a fuel which is heavily diluted with a fertile material (i.e. a material which by neutron absorption forms another fissile material) we use a fuel which consists almost entirely of fissile material, the moderator clearly becomes unnecessary. In such a reactor the neutrons are not slowed down, and reactors of this type are therefore called fast reactors. There are two main advantages in this type of reactor. Firstly, even the best and purest moderators give rise to some useless absorption of neutrons. Secondly, while in any thermal reactor system most of the neutrons that are captured by the fissile material cause fission to take place, some are captured without causing fission and cause the loss not only of the neutron but of a further atom of fissile material. In a fast reactor nearly every neutron striking a fissile atom causes fission to take place. Fast reactors are thus potentially capable of very much better neutron economy than any thermal reactor. With this good neutron economy, it is possible to achieve an arrangement in which the number of new fissile atoms produced within a fertile material that can be incorporated in the assembly is greater than the number of fissile atoms that are destroyed. In fact, while releasing heat which could be used in generating electrical power, we breed additional fuel. For this reason reactors of this type are

frequently referred to as breeder reactors, and this characteristic makes it extremely desirable to develop the fast fission reactor for use in the industrial programme.

There is an additional reason why development of the fast breeder reactor is necessary. In discussing the primary thermal reactors in which natural uranium is used as a fuel, it has been pointed out that they produce plutonium as a by-product, and that in order to achieve a balanced nuclear power industry it is necessary to devise reactors in which this by-product plutonium can be used as a fuel. To some extent this can be done by burning the plutonium in thermal reactors, which for economy must have sufficiently high ratings. But when plutonium is subjected to neutron irradiation, some of the atoms absorb neutrons to form higher isotopes which have even greater neutron absorption cross-sections. For this reason the use of plutonium in a thermal reactor cannot give rise to high neutron economies. The absorption cross-section of plutonium and its isotopes is much lower for fast neutrons than for thermal neutrons, and plutonium is therefore much better as a fast reactor fuel than it is as a thermal reactor fuel.

At present the United Kingdom Atomic Energy Authority is constructing a prototype fast reactor at Dounreay, in the north of Scotland. It is interesting to note that because the ultimate desirability of this system and the immense problems involved in developing it were realized at an early stage, the Dounreay project was put in hand before construction was started on the Calder Hall reactors.

The arrangement of the Dounreay fast reactor is shown in figure 5. Because sufficient quantities of plutonium were not available for research purposes, the reactor will use highly enriched U^{235} as its fuel. It will, however, be possible to insert some plutonium fuel elements so that information on their metallurgical and nuclear physical behaviour can be obtained simultaneously with the other scientific and technological development work that will be carried out on the prototype. The fuel elements, in the form of tubes made of enriched uranium, each of which is enclosed in a can of very special construction, are arranged in a cylinder about 2 ft in diameter and 2 ft long. From this cylinder a heat release of 60 MW must be achieved: this necessitates heat-transfer rates of up to $\frac{2}{3}$ kW per square centimetre of fuel element. It is obvious that in order to achieve such a high heat-transfer rate it is desirable to use a liquid metal coolant. In order to minimize the ancillary problems in the development of the reactor it was decided to use sodium-potassium alloy having a melting point sufficiently low to ensure that the metal will not become solid at the temperatures to which the reactor will normally fall when it is shut down. The small reacting core is surrounded by rods of fertile material in which the excess neutrons will be absorbed and the secondary fuel bred. Initially uranium will be used as the fertile material, but one of the advantages of the fast reactor is that it enables us to gain a point of access to the thorium cycle. When subjected to neutron bombardment, thorium forms, by neutron absorption and subsequent decay, an isotope of uranium (U^{233}) which is fissile. This isotope has advantages as a secondary fuel both because its neutron emission characteristics in thermal reactors are better than those of either plutonium or U^{235} and because the metallurgical properties of U^{233} are far more favourable than those of plutonium. Thorium can, of course, be used as a fertile material in any reactor where spare neutrons are available for absorption, and it is possible to introduce it into thermal reactors that are so arranged as to have excess neutrons.

The fast reactor, and indeed all reactors having very high ratings, gives rise to safety problems which we have not had to consider in connection with the thermal reactors that have been discussed. The heat output of the reactor core is extremely high, and its mass and heat capacity are low. If, therefore, there were a complete interruption in the flow of coolant, it might happen that the heat emission from the fuel would melt the reactor core. At Dounreay the primary safeguard against this is a multiplicity of cooling circuits, each with its own pump and divided into separate groups with distinct sources of power supply. A catastrophe is therefore almost inconceivable, but should it happen there is an even more remote possibility, that the sodium–potassium alloy might ignite, even though the liquid metal is buffered with an inactive gas, and by volatilizing the fission products present in the fuel elements would disperse active material over the district. In order to guard against this, the whole assembly has been encased in a metal sphere, the diameter of which is 135 ft and which has been designed to be of sufficient strength to withstand the calculated pressure of the products of combustion if this most unlikely incident should occur.

A fast reactor presents problems of tremendous difficulty, but by far the most complex and difficult lie within the fuel elements themselves. Although

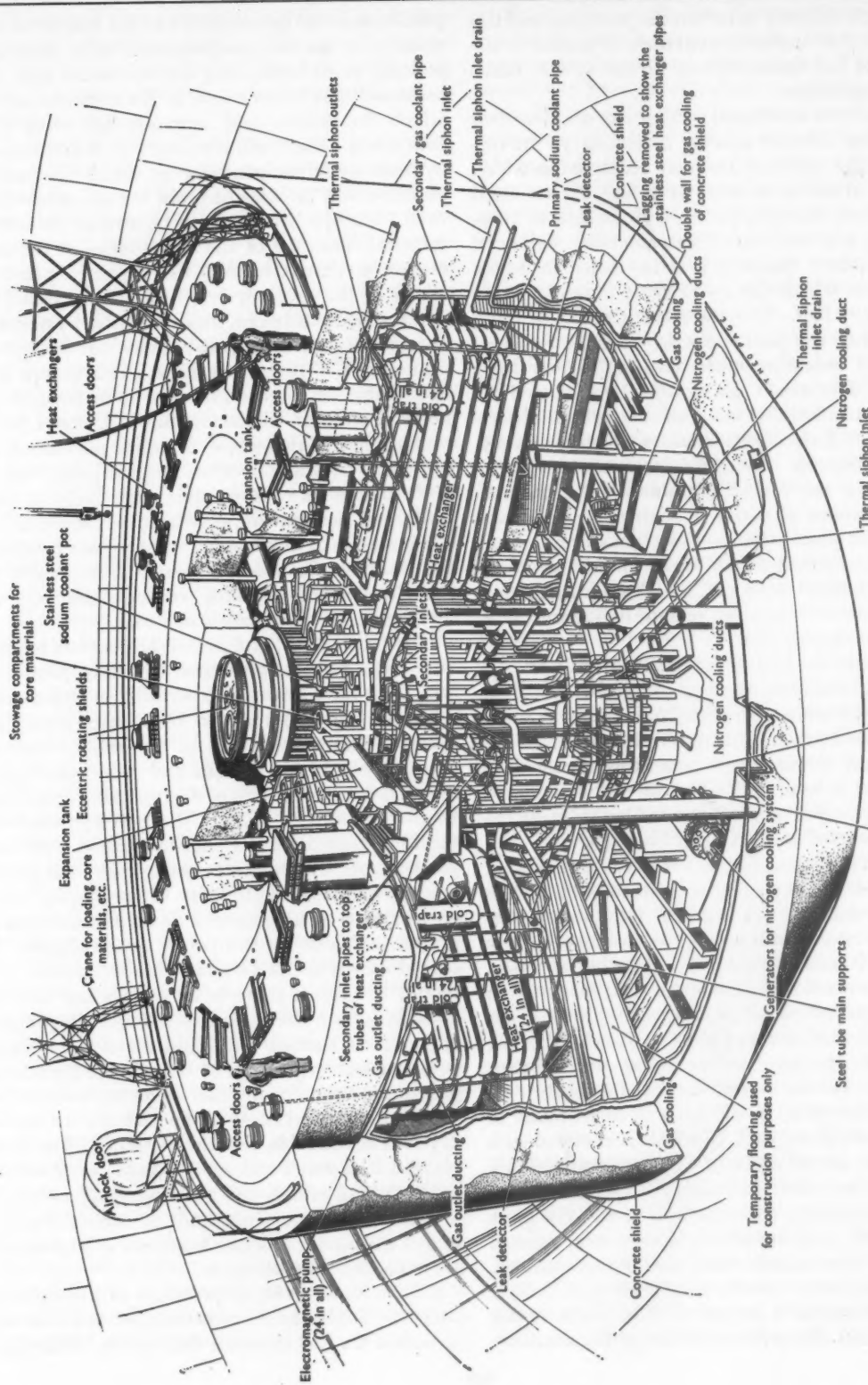

FIGURE 5 – *General arrangement of the Dounreay fast reactor.* (*By courtesy of* Nuclear Power.)

heat flows of $\frac{2}{3}$ kW per square centimetre from a surface are not frequently demanded in industrial practice, they can be achieved. But in a reactor, the heat which is thus being conveyed away from the surface is generated by fission within the mass of metal in the fuel elements, and uranium has not a high thermal conductivity. The temperature gradients within the fuel element are therefore considerable. Uranium has two allotropic change-points, and the change of volume at the upper of these two is so considerable that to pass through it would so alter the nuclear physical characteristics of the core as to make stability of control questionable. The creep rates of uranium at elevated temperatures are high, and it is therefore necessary to give the fuel some support from the can. But uranium is also a reactive metal, and the choice of canning materials which will give this support, which have suitable low neutron cross-sections, which have a sufficiently high thermal conductivity, and which are not chemically reactive with uranium at the temperatures which will be experienced in the reactor, is a difficult problem.

Within the life of the fuel elements inside the core quite a high proportion of its atoms will be destroyed by fission; in order to make a fast reactor operate economically it is probable that burn-up rates of at least 1 per cent must be achieved before removal of the element from the reactor for re-processing. Some of the fission products are gaseous and are capable of building up pressures within the metal, while the formation of the others necessarily tends to break down the initial structure and weaken the material. There is therefore a serious danger that the metal of the fuel element may itself disintegrate.

The prototype reactor, which will be in operation at Dounreay in 1958, is designed to provide facilities for the investigation of these and other problems. It will not provide a basis on which fast breeder reactors can be designed for use in industry. Before this can be done, the Dounreay prototype will have to be followed by a pilot reactor, and it is probable that supply authorities will not be in a position to place orders for commercial types until the mid-1960's.

Fuel element problems are by no means confined to fast reactors; indeed, it is probably true to say that for any type of reactor that can be built, the performance will for many years to come be limited by the fuel element. Moreover, the fabrication and canning of fuel elements, and their subsequent treatment after irradiation, are expensive and complicated processes. It is with a view to eliminating these problems of the solid fuel element that thought has been given to homogeneous systems, in which the fuel is circulated in solution or in suspension through the reacting core. Basically the simplest of these systems is probably the one in which the liquid fuel consists of a solution of uranium sulphate in heavy water, and a small reactor of this type has been built in America. Although it has great attractions, even more unsolved problems are involved than with the fast reactor. In order to be economical and practical, the system has to work under high pressures and temperatures, so that all the problems of corrosion by water of materials of construction are likely to arise. In addition, there is both chemical and nuclear breakdown of the fuel, which introduces impurities into the system, making the corrosion problem even more difficult. Some of the fission products are gaseous, and these must be removed. Figure 6 shows a schematic flow diagram. There are alternative homogeneous systems in which the fissile material is used as a molten salt or in which it is in solution or suspension in liquid metals, but none of these systems removes the acute difficulties that have to be solved.

Moreover, the homogeneous systems must inherently demand far greater skill on the part of the operators. A plant in which reactors of the Calder Hall type are installed is no more difficult to operate, from a works management point of view, than a conventional power plant; in fact, in some ways it offers fewer problems. Fabrication of the fuel elements will be carried out in factories specializing in these processes, and the completed fuel elements will be transported to the power station site for insertion into the reactor. The highly specialized chemical treatment of the irradiated fuel elements for a national industrial programme for nuclear power production will be done in no more than two or three chemical factories, so located that any radioactive effluents can safely be discharged into tidal water. They will be staffed with men who are trained as chemists and chemical engineers, and are experienced in the running of such plants. By contrast, in order to make a homogeneous system work satisfactorily, it is almost certain that there must be continuous chemical processing of the fuel; thus each power plant will contain its own chemical plant, carrying out a highly specialized process and giving rise to a certain amount of active effluent. While there can be considerable freedom in choice of sites for reactors using solid fuel elements, it thus appears that the selection of sites for homogeneous reactors will be more difficult

FIGURE 5 – *General arrangement of the Dounreay fast reactor. (By courtesy of* Nuclear Power.)

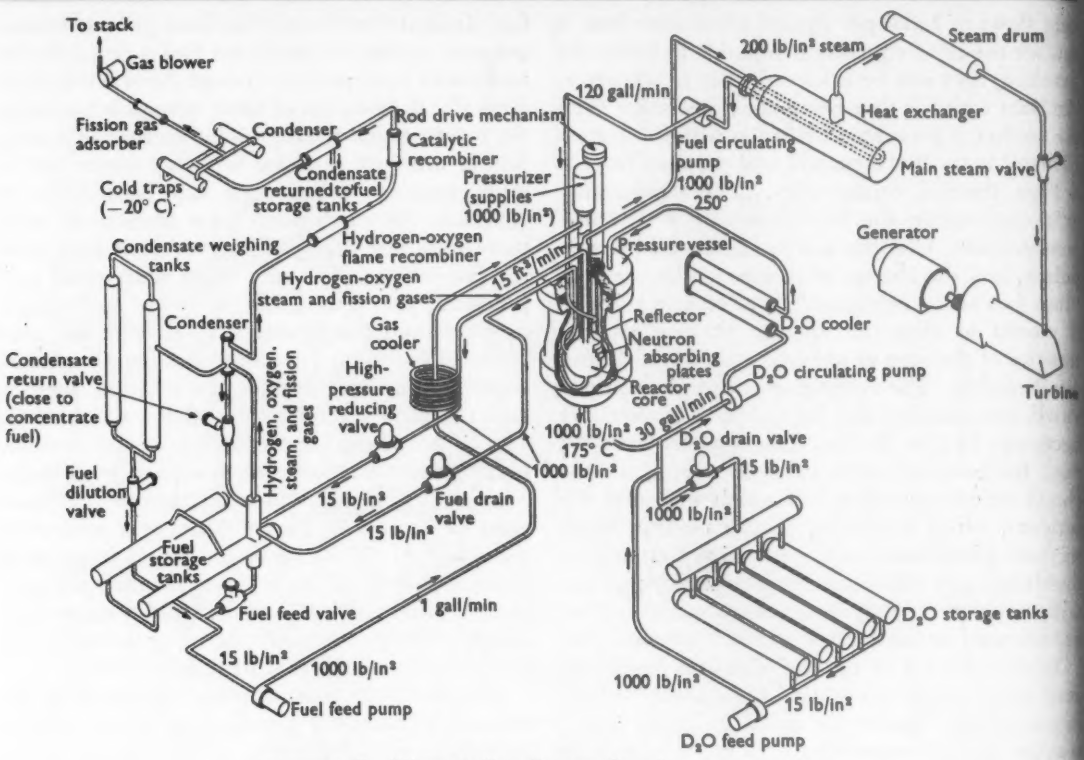

FIGURE 6 – *Schematic flow diagram for a homogeneous reactor.*

and that it might be found that they can be placed only on coastal sites, from which effluents can be discharged into the sea at an appreciable distance off-shore. Each station will also require a staff competent to control a complex chemical process.

Although among some experts there is great enthusiasm for the homogeneous system, and although the advantages of ridding oneself of the problems of the solid fuel elements are very attractive, it seems possible that not only the technological problems of design and construction, but the problems of subsequent operation will postpone into a fairly distant future the date when they will become widely used.

All the reactors so far discussed in this article have been considered from the point of view of their use in large land-based stations, and it is towards the solution of these problems that most British work has been directed in the past. The primary reason for this lies in the fact that the most urgent need in Britain is for reactors which will help to relieve the demands for conventional fuels, which are outrunning supplies. It is in the field of the large land-based reactor that atomic energy can make the greatest contribution in this respect. It would, however, be wrong to forget that even though both the national need and the market are smaller, there is also a demand for reactors which, instead of producing, say, 150 MW of electrical power, are capable of producing 20–30 MW of power. These are the reactors for which there is the greatest need in overseas countries which have not yet achieved a high state of industrial development; reactors of these and smaller sizes would also find uses on mobile platforms such as steamships.

It is almost inevitable that the cost of power produced in such small reactors should be higher than the cost of power produced in large land-based reactors. On the other hand, in certain specialist applications such higher costs may be tolerable. Almost certainly, natural uranium can be used in such small reactors only if heavy water is used as a moderator; if graphite, beryllium, or light water are used for moderation, the use of slightly enriched fuel would seem to be inevitable. We have already seen that for the highly specialized application of submarine propulsion the Americans have developed a reactor both moderated

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FIGURE 7 – *General view of a Calder Hall reactor.*

and cooled by light water, and British work on a similar project is at present proceeding. There can be no doubt that the Americans have achieved considerable success in this abnormal application. Whether the system can be so cheapened and simplified as to make it attractive, for instance on merchant vessels and for the small land-based installations, remains at present a matter for speculation.

A system which has hitherto not been mentioned, and which might also show suitability in this field, is one in which heavy water is used as a moderator and a gaseous coolant is used; the Russians have done some work on such a system.

The demand for compact and lightweight nuclear reactors for special applications will lead to the design of plants in which the conditions are met only by the use of special materials and of which, for that reason, the capital costs are high. These special applications, however, will enable techniques to be developed which reduce the difficulties and costs of construction and so bring prices down to the level at which installation can be justified in more normal cases. Meanwhile new special cases will arise demanding new exotic and expensive solutions, and these in their turn will in time become normal practice.

NUCLEAR FUSION

Beyond all the possibilities which have been discussed in this paper, lies that of the nuclear fusion process. In all the power plants that have been discussed, heat which is converted into electrical or mechanical energy arises from the fission of atoms at the end of the periodic table. It is, however, possible to release heat by the fusion of light elements. In order to do this, the atoms to be combined must be accelerated to velocities corresponding to temperatures above 1 000 000°C. At present we have only the most elementary ideas of how this might be accomplished on the industrial scale, and it will be many years before we can supply information to the engineers which would enable them to build the first infantile prototype of such a system. Even with the possibility of breeding, there must be some limit to the amount of fissile material which is available as an industrial fuel. When the nuclear fusion process can be harnessed to industrial power production, this limit will be removed and it would not be unreasonable to predict that power plants using the nuclear fusion principle will be in industrial use early in the twenty-first century.

Spore liberation in higher fungi

C. T. INGOLD

The late Professor A. H. R. Buller showed mycologists that the way to a proper understanding of the wonderful range of form in fungi was to study them as living mechanisms involved in the production and liberation of spores. This article reviews some interesting recent work in this field with special reference to a basidiomycete and an ascomycete, and shows how highly the larger fungi are organized in respect of the liberation of spores.

In higher fungi (Basidiomycetes and Ascomycetes) the conspicuous part, the fruit-body, is essentially an apparatus concerned with the production and liberation of spores. The feeding mycelium is normally hidden as branched hyphae in the nutrient substratum. In general the spores of higher fungi are dispersed by wind, although there are conspicuous exceptions, such as the stinkhorn (*Phallus impudicus*) with spores spread by flies; the subterranean truffles (*Tuber* spp.) with spores dispersed by rodents; and the beautiful little dung fungi (species of *Ascobolus*, *Sordaria*, and *Coprinus*) with spores normally disseminated through the alimentary canal of herbivorous animals [1]. In dispersal as a whole there are commonly three episodes: spore liberation, the actual dispersion through the air, and the coming to rest of the spores on the substratum. Here we are concerned with the first episode.

Once the spores get into the turbulent air, the study of their dispersal is essentially a meteorological problem, since, because of their small size (most being smaller than the water droplets in mist) their movement is determined by the behaviour of the air mass in which they become incorporated. It should be emphasized that the first step in dispersal is not merely the freeing of the spores from immediate contact with the parent body, but also the launching of the spores into the turbulent layer of the air so that their subsequent dispersal is assisted.

By way of illustrating the problems involved in spore liberation two fungi common in Britain, one a basidiomycete (*Ganoderma applanatum*) and the other an ascomycete (*Daldinia concentrica*) will be considered here.

Ganoderma belongs to the Hymenomycetes, the largest group of Basidiomycetes, characterized by having its spore-producing surfaces (hymenia) exposed at maturity. In most fleshy toadstools (Agaricaceae) the hymenium covers the surface of vertical lamellae (gills), but in Polyporaceae, to which *Ganoderma* belongs, the hymenium lines vertical pores.

The spore-producing unit of the hymenium is the basidium, a single cell with a characteristic development, which produces four basidiospores externally on fine sterigmata. These microscopic basidia are elongated at right angles to the hymenial surface, and are thus normally horizontal. Each spore is poised asymmetrically at the end of its sterigma, and very near to its point of attachment is a small projection (hilum). Just before the discharge of the spore a drop of fluid suddenly appears at the hilum, grows to a certain definite size, and then the spore is shot away, carrying the drop with it. Fungal spores discharged in this manner have been termed 'ballistospores'. Shortly after the discharge of one spore another is shot away, and so on until all four have gone. Then the basidium slowly collapses. In *Ganoderma* the distance of discharge is about 0·005 cm[1]. In other Hymenomycetes it tends to be greater, but seldom exceeds 0·02 cm.

The mechanism of violent spore discharge in Hymenomycetes is not clearly understood. A. H. R. Buller [2] considered that the drop originated at a small distance from the sterigma and was essentially exuded by the spore. This is clearly shown in his figure of discharge in the gelatinous fungus *Calocera* (figure 6). Others consider that the drop exudes at the junction of the spore with the sterigma. D. Müller [3] has made a cinematographic study of ballistospore discharge in the mirror-yeast *Sporobolomyces*. He claims that sometimes the drop of fluid is discharged, leaving the spore behind on its sterigma. His picture of discharge is that rupture of the turgid sterigma occurs at its junction with the spore, and that a drop of fluid is expelled which ordinarily carries the spore with it. Another theory, strongly supported by

[1] Unpublished determination by the author.

FIGURE 1 – Ganoderma applanatum. *Fruit-bodies growing on beech. Photograph by Dr Somerville Hastings.*

FIGURE 2 – Daldinia concentrica. *Stromata on ash.*

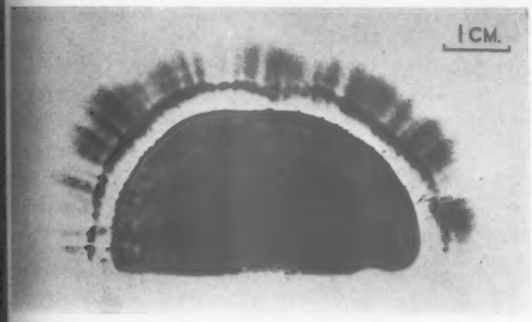

FIGURE 3 – Daldinia concentrica. *Black spore deposit formed overnight around a thick slice of stroma laid horizontally on a glass plate.*

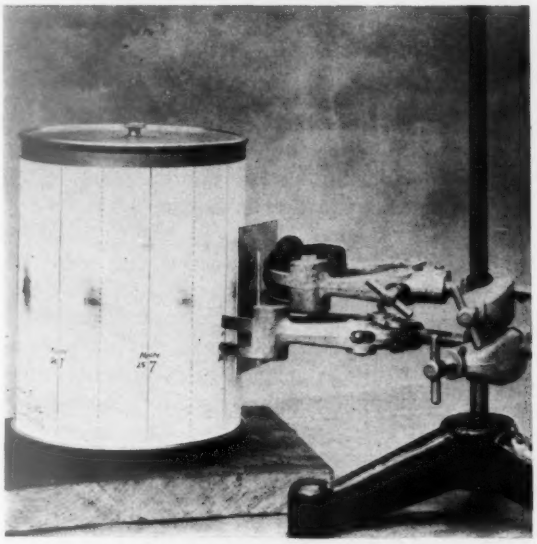

FIGURE 4 (*right*) – *Apparatus for studying spore discharge in* Daldinia. *The stroma is held in a clamp and spores are shot through a vertical slit in a metal screen; being sticky, they adhere to the white paper on the drum, which makes one rotation in a week.*

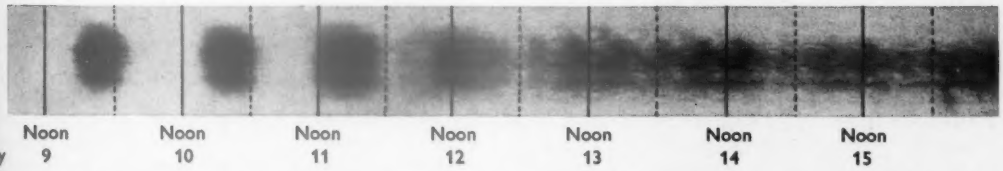

FIGURE 5 – *Spore trace obtained using apparatus shown in figure 4. Temperature and humidity were kept fairly constant (temp. 20·5–23° C.; rel. hum. 92–94 per cent) and the fungus was in continuous darkness. The nocturnal rhythm of spore discharge has, however, continued for some days. The interrupted vertical lines show the positions of midnight and the uninterrupted lines positions of noon.*

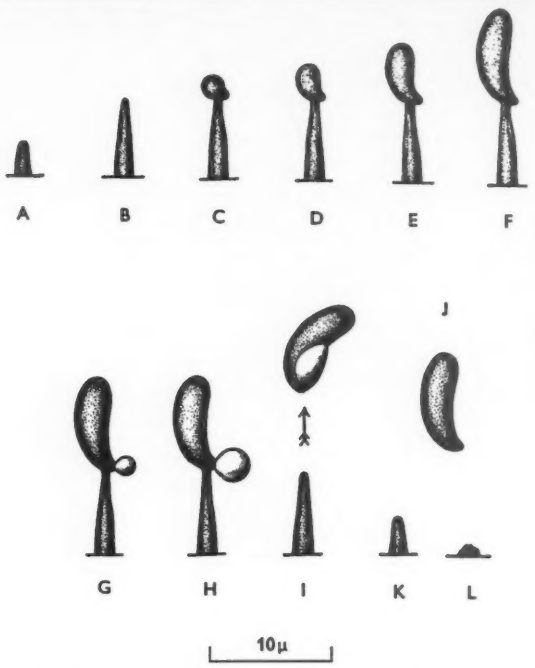

FIGURE 6 – Calocera cornea. *A–L, stages in the development of the basidiospore at the end of the sterigma and subsequent spore discharge. After Buller* [2].

the observation of A. E. Prince [4], is that there is a cross-wall at the junction of the spore with its sterigma. Both spore and basidium are turgid cells, and at this junction strains are set up, the tip of the sterigma and the spore both tending to round off. These strains are released suddenly, with the result that the spore springs off from its sterigma. This type of discharge is well known in certain lower fungi belonging to the genus *Entomophthora*. However, if this is the true mechanism it does not bring the exuded drop into the picture. It has also been suggested [5] that the surface energy of the drop might be mobilized for spore discharge, but the evidence in support of this view is very slight. It must be admitted that the problem of spore discharge from the basidium is not yet solved.

Ganoderma applanatum (figure 7) is one of the very few fungi with a perennial fruit-body. A single specimen may remain active for five years or more, adding an annual increment to the tube layer each summer. The fruit-body consists of a hard woody semicircular bracket, triangular in vertical section (figure 1), broadly and firmly attached to the tree, often beech, ash, or oak. The bracket may be half a metre or more across. The pores or tubes occur on the under surface. In its growth each is positively geotropic. The tubes lined by hymenium are long (often several centimetres) and very narrow, with an internal diameter of only about 0·01 cm (figures 8–10). However, because of the accuracy of the geotropic growth of the pores and of the great rigidity of the bracket, the tubes originate and remain in a strictly vertical position. They increase in length during the late spring and summer, but rest during the cold seasons, to resume their growth in the spring. Active hymenium is produced not only in the extensions to the tubes made in the current season, but also in regions of the tubes which are two or three years old. The active hymenium, with ripe basidia, does not extend quite to the orifice of each tube but stops about half a millimetre short of it. In this region, including the growing free margin of the pore, the hymenium is not yet mature.

Each year, spore discharge starts in May and continues until September, and during this time the output is continuous. It has been calculated [2] that a large specimen liberates 20 million spores a minute continuously for the five or six months of its annual activity. An unusual feature of this fungus is that discharge goes on even during prolonged periods of drought [6]. *Ganoderma* is clearly a xerophyte: this xerophytism is probably partly due to the hard lacquered upper surface from which water loss is slow, and partly to the very narrow hymenial tubes, within which the air must remain nearly saturated. However, these features alone would not explain the xerophytism.

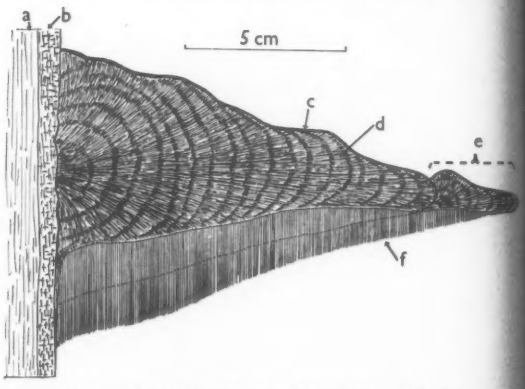

FIGURE 7 – Ganoderma applanatum. *Vertical section of a small fruit-body growing on ash. a, wood; b, bark of ash tree; c, upper 'crust' of fungus; d, zoned fibrous cap tissue formed in first year; e, additional cap tissue produced in the second year; f, hymenial tubes (the dotted line indicates the boundary between the tubes formed in the first year (above) and in the second (below)).*

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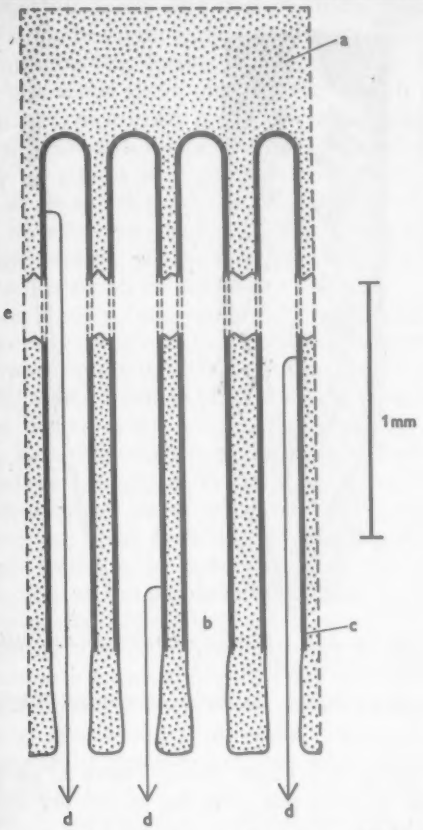

FIGURE 8 – Ganoderma applanatum. *Diagram of longitudinal section of hymenial tubes. a, cap tissue; b, hymenial tube; c, active hymenium shown by thick black line; d, trajectory of a discharged spore; e, gap in the diagram corresponding to about 20 mm in the actual specimen or 760 mm at the scale of this figure.*

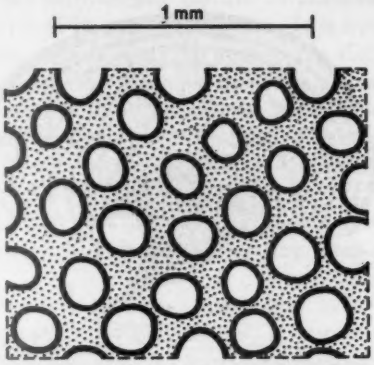

FIGURE 9 – Ganoderma applanatum. *Transverse section of hymenial tubes. The thick black line around each pore is the hymenium.*

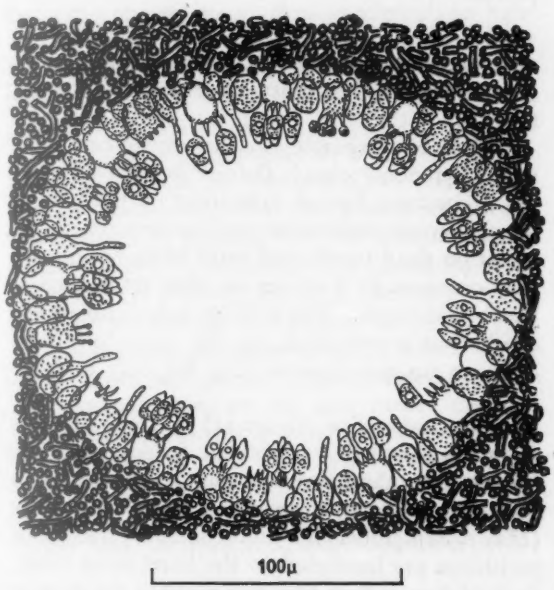

FIGURE 10 – Ganoderma applanatum. *Drawing of a single hymenial tube seen in transverse section. The hymenium consists mainly of thin-walled basidia at various stages of development. The rest of the tissue is composed of intertwining thick-walled branched hyphae.*

There must be substantial water conduction from the feeding mycelium in the tree trunk to make good loss by evaporation. It is worth observing in passing that lack of knowledge of how water and food are conducted is one of the greatest gaps in fungal physiology.

It has already been noted that the pores are only 0·01 cm wide and that the spores are shot to a distance of 0·005 cm, that is to say into the middle of the tube. They then fall in the still air within the tube and finally emerge below the bracket into turbulent air. It is to be noted that there is here no margin of safety. If the tubes were not exactly vertical this escape would be impossible. The spores are sticky, and if they were to touch the lining of the tube they would become permanently stuck, yet in sections such stranded spores are rarely seen. It seems possible that there is some force keeping the spores in mid-stream during their fall down the hymenial tubes: perhaps an electrostatic repulsion is involved.

The story of spore liberation in toadstools and bracket fungi generally is essentially the same as in *Ganoderma applanatum*, but the special features of that fungus are its longevity, in contrast to the ephemeral nature of most toadstools; its xerophytism, in contrast to most Hymenomycetes, which are either incapable of withstanding drought or can endure it only by passing into a

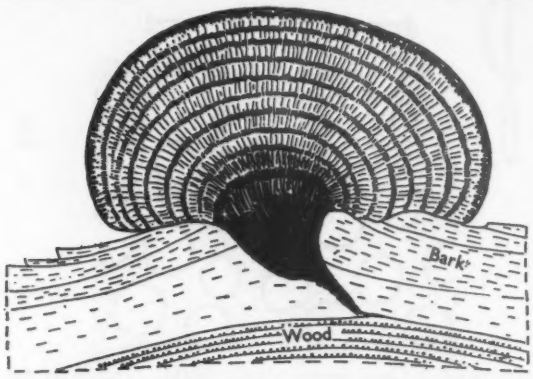

FIGURE 11 – Daldinia concentrica. *Vertical section of a stroma on ash. The black dots within the surface are perithecia.* (× 1·5)

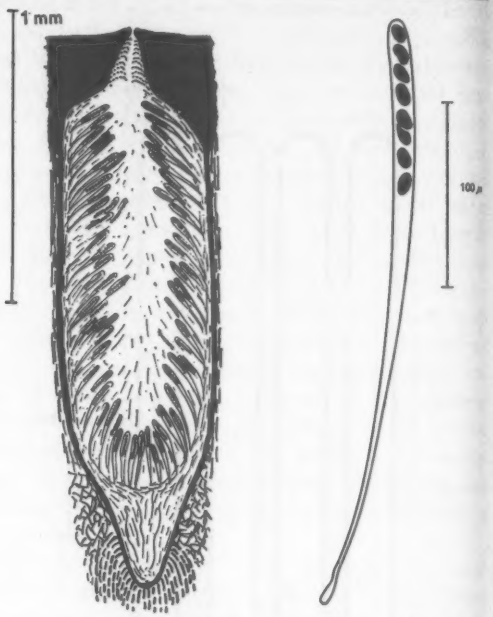

FIGURE 12 (*left*) – Daldinia concentrica. *Single perithecium in vertical section.*

FIGURE 13 (*right*) – Daldinia concentrica. *Single ascus.*

state of suspended activity; and its great rigidity, in contrast to the flimsy structure of so many fungi.

Our second example, an ascomycete belonging to the Pyrenomycetes, is *Daldinia concentrica* (figure 2), a common fungus appearing as hard black hemispherical cushions several centimetres in diameter on dead trunks and large branches of ash; very occasionally it occurs on other trees, such as beech and birch. The feeding mycelium in the dead wood is perennial, but the individual fruit-body or stroma remains alive for only a single season.

In vertical section (figure 11) it is seen that the stroma is zoned in a concentric fashion, and this feature gives the fungus its specific epithet. If a specimen is examined during its period of activity (May to September) it is found that very numerous perithecia are immersed in the hard outer crust. Each of these is flask-like, and opens to the outside by a narrow canal. Within, lining the walls of the perithecium, are numerous asci in various stages of development (figure 12). The ascus is the spore-producing unit of Ascomycetes (figure 13): it has a characteristic development and at maturity is a turgid living cell containing usually eight ascospores. In *Daldinia* the ripe spores are almost black. All round the asci, and completely filling the perithecium, is a mucilaginous slime. In spore discharge a single ascus elongates up the perithecial neck-canal and, when its tip reaches the outside, bursts, shooting its spores to a distance of 0·2–1·4 cm. As soon as one ascus has discharged, another elongates up the canal, and so the process goes on. Unlike the basidium, there is no mystery about the mechanism of discharge of the ascus. It is a turgid cell which finally bursts at an apical region of weakness, and the spores are squirted into the air.

It is worth remarking that the ascus is a much more powerful spore gun than the basidium. The recorded distances of basidiospore discharge vary from 0·005 cm to 0·1 cm. So far as asci are concerned, the distance of discharge may be as low as 0·1 cm but is more frequently of the order of 1 cm: in *Dasyobolus immersus* a horizontal throw of 60 cm has been measured. The performance of *Daldinia* can easily be seen if a median slice a few millimetres thick is cut from an active stroma and laid on its side overnight on a horizontal sheet of glass. There develops, parallel with the perithecia-studded edge of the slice, a thick black deposit forming a band about 1 cm wide separated from the stroma by a spore-free zone with a width of about 0·2 cm (figure 3). The fact that the spores are spread out in this way is easy to explain. The contents of the ascus may stick together on discharge as a relatively large projectile of eight spores, or break up into smaller projectiles of fewer spores, even single ones. For a given initial velocity the distance (d) of horizontal discharge of microscopic spherical projectiles is given by $d = Kr^2$, where K is a constant and r the radius of

the projectile. Thus with a given initial velocity of discharge the larger eight-spored projectiles will travel considerably further than a projectile consisting of a single spore. In conformity with this, microscopic examination of the spore deposit shows that towards the outer fringe the spores are mainly in groups of eight, while on the inner fringe single spores predominate [7]. As in *Ganoderma*, the spore output by *Daldinia* is very great. A single stroma of average size may liberate 100 000 000 spores overnight.

It has already been remarked that the stroma lasts for only a single season. In Britain, it appears and grows rapidly to its full size during the damp but still warm weather of September. The perithecia, however, do not mature until the late spring of the following year. Once spore discharge commences, usually early in May, it continues until September, and as with *Ganoderma* it appears to be independent of external water supply [8]. *Daldinia* seems to be a xerophyte of the *Cactus* type. The stromatal tissue represents a water reserve on which the perithecia draw, so that discharge can take place even in the dryest weather. If a stroma is detached from the tree in early summer and placed in a dry room, it will continue to discharge spores for several weeks. Its initial specific gravity is just over 1·0, but when discharge ceases this is reduced to less than 0·3, hardly any change occurring in the actual volume of the stroma. When attached to the tree there is evidence to show that, as the water reserve is used up, it is replenished from the host [8]. In its lack of reliance on external water *Daldinia* appears to be unique, and it is quite unlike other Pyrenomycetes, which can discharge their spores only after wetting by rain.

Another outstanding feature of *Daldinia* is the periodicity of its spore discharge. It is nocturnal. The vast majority of the spores are discharged during the period from 9 p.m. to 9 a.m., and very few from 9 a.m. to 9 p.m. Periodicity of discharge seems to be a feature of many Pyrenomycetes, although not all are nocturnal. *Sordaria fimicola*, for example [9], a very common dung species, is diurnal. In the Basidiomycetes, on the other hand, daily periodicity of discharge does seem to occur.

In *Daldinia* the periodicity has been investigated to some extent [10]. If a stroma is kept continuously in the dark at a constant temperature, periodic spore discharge continues for from 4 to 10 days (figures 4 and 5). If kept in continuous light, periodic discharge also continues, but for a shorter time. Both in continuous light and in continuous darkness the discharge rate ultimately settles down to a steady level with no clear periodicity. If, however, the old periodic conditions of illumination are again imposed, the periodic discharge immediately begins again. We have in *Daldinia* an example of an endogenous rhythm continuing after the periodic conditions have ceased to operate. A very similar state of affairs has been found to occur in the coprophilous phycomycete *Pilobolus* [11, 12]. However, in *Sordaria fimicola* there is no endogenous rhythm [9].

In *Ganoderma applanatum* and in *Daldinia concentrica*, chosen as representatives of Basidiomycetes and Ascomycetes, we see two rather different types, each discharging vast numbers of spores. To some extent these two examples are rather unusual, particularly in their water relations, but they serve to show how highly organized are the larger fungi in relation to spore dispersal.

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Plants and their water supplies

J. P. HUDSON

The practice of irrigation is so ancient, and such vast sums are now being expended on new irrigation schemes, that it might be supposed that the basic principles governing the efficient supply of water to plants are well known. In fact, however, for many crops some seemingly simple questions, such as the best time to apply water, cannot yet be answered. This article reviews some recent work in the field of irrigation research and stresses the necessity for more experimental work if full value is to be obtained from money spent on irrigation schemes.

The capacity of a plant to grow is limited by its heredity, and nothing the farmer can do can increase yield beyond that level, but up to the limit set by genetics the harvest produced by any crop is determined by its response to the environment. The plant environment is extremely complex, and is affected, among other factors, by the weather, soil, cultural practices, competition with other plants, and the incidence of diseases and pests. Yield is determined by the net effects of all these factors on growth, and the amount by which actual yield falls short of possible yield reflects the extent to which the controlling factors themselves fall short of the ideal.

Some factors, particularly those concerned with light and temperature, are difficult to control, and the farmer philosophically plans his cropping to make the best of local conditions, but other factors may be more readily controllable. Where this is so, it is important to know two things. Firstly, at what level each particular factor is likely to produce the best yield, and secondly, how far towards that level it will pay the farmer to go.

Because of their natural tolerance to sub-optimal conditions, plants can produce reasonable yields under moisture conditions that are far from ideal. It is not easy for a farmer to assess the loss of yield caused by incorrect irrigation practices, because he usually has no standard by which to form his judgment. If plants were less robust, and soils less accommodating, so that crops died at the first sign of adverse conditions, we might by now have learned how to grow them perfectly. In fact, agriculture depends on the resilience of plants to adverse conditions, yet that very characteristic often masks responses that could point the way to improved methods of management.

IRRIGATION MANAGEMENT

So far as water is concerned, irrigation requires three questions to be answered. (1) When should water be applied? (2) How much water is needed? (3) What is the best way to do the minimum damage to soil structure when putting water on the land? The first is a question of crop physiology, the second is largely dependent on meteorological conditions, while the third problem lies in the fields of soil science and engineering. Although the three questions are listed in their logical sequence, and perhaps in their order of relative importance to the farmer, the present state of our knowledge of the answers is anything but logical.

Irrigation engineers have provided admirable solutions to the third of these questions. The problems of water conservation, distribution, and application to the land are well understood, and efficient methods of irrigation are available to meet the needs of most farmers, once those needs can be formulated precisely. Soil scientists are able to describe the characteristics of a soil in terms, such as infiltration rates, moisture-holding capacity, and rates of water movement, which enable the best method of water distribution to be specified for each type of soil.

In the past, the second question has been answered largely by guesswork. If the guess was wrong and too little water was applied, then plant growth would be depressed through lack of moisture, since the soil would not be adequately re-wetted and part of the root zone would remain too dry for roots to function well. On the other hand, application of too much water might result either in disastrous waterlogging or in loss of surplus water to drainage, carrying with it valuable plant nutrients.

Ideally, the object at each irrigation is to re-wet the whole volume of soil occupied by roots to the condition of moisture optimal for the growth of the plant concerned. This is usually taken as being the 'field capacity', i.e. the maximum amount of water which a well drained soil can hold against gravity.

FIGURE 1 – *Glasshouse subdivided into brick-lined beds for experimental work on the water-relationships of tomato plants.*

FIGURE 2 – *Four lysimeters with concrete bases and drains leading into deep trench (on right) where drainage water from each bed can be collected and measured. Each bed is subjected to a different water regime throughout the life of the plants, with a sub-treatment in each lysimeter in the early stages.*

Simple and obvious though it seems, there is still no really satisfactory way of deciding in the field how much water should be added, but in the last few years a new approach has yielded rewarding results. It has been shown by H. L. Penman [1] and others [2] that the rate of moisture loss from a soil can be deduced from a study of certain readily recorded meteorological data, such as hours of sunshine and rate of precipitation, without direct measurements of the actual moisture status of the soil. This is a tremendous step forward, since the necessary local meteorological observations can easily be made and from them information can be supplied to the farmer on the rate of water loss from his own particular soil. He can thus be advised how much water he should apply to ensure adequate re-wetting without waste.

WHEN TO WATER

This kind of knowledge does not, however, indicate when to water, which is an essential key to successful irrigation.

Plants suffering from severe shortage of water show various visual symptoms of distress, the most obvious of which is wilting of soft stems and leaves. However, before these drastic visual symptoms occur there may be a marked slowing down of growth. Since it is difficult to assess retarded growth, farmers and gardeners often believe that so long as a plant looks all right it is growing well. This belief suggests that there is no need to apply irrigation water until just before plants wilt; it will certainly prevent them from ever showing visible signs of distress and will often produce apparently satisfactory yields. Indeed, workers of the University of California [3] have produced a good deal of experimental evidence that appears to support the view that there is little point in irrigating until nearly all the available water has been taken from the soil. This view sanctions the application of irrigation water in relatively infrequent, but heavy, doses.

But there is also much evidence [4] that appears to conflict with this view, and suggests that, as a soil dries out, growth falls off long before plants start to wilt. In other words, yields may be seriously reduced by shortage of water without the plants ever having shown any visible signs of distress at all.

Results of five years' experiments at Sutton Bonington [5, 6] have suggested a possible bridge between these two apparently contradictory results, both of which may be valid in different circumstances. It has been found that the same volume of water may produce different yields, depending on whether it is applied in a few heavy applications or many lighter ones, a result that may obviously be of the greatest importance.

The water in a soil that is available to plants lies between two convenient but rather ill-defined limits, namely field capacity and permanent wilting point. The latter is the point at which plants flag and will not recover unless they are watered.

FIGURE 3 – *Tomato plants excavated at the end of the growing season to study effects of the water regime on distribution of roots. Each white peg on the exposed face marks the position of four roots. Note the vacuum gauges of tensiometers installed to measure soil moisture tensions.*

FIGURE 4 – *Lettuce plants growing in a brick-lined bed subjected to a particular water regime. Corner plants were removed at intervals of seven days to compare growth rates under different systems of irrigation.*

SOIL MOISTURE TENSION

The progress of water uptake from a soil can be followed by measuring one or other of the characteristics of soil moisture [7]. Measurement of soil moisture tension is useful, because it is related to the forces that must be overcome when a plant takes up water. One convenient method of assessing tension at the wetter end of the 'available' range is to install soil moisture tensiometers. These consist of unglazed porous porcelain pots connected by tubes to gauges or manometers, each instrument being filled with water and its pot buried to the required depth in the soil. It is assumed that the water in the instrument becomes continuous, through the pores of the pot, with the moisture filling the fine soil capillaries. As the soil dries out, the tension of the remaining moisture in the soil increases, is transmitted to the water within the tensiometer, and is recorded by its gauge, which responds to rewetting of the soil by returning to a low reading (figure 5). Other methods are more useful for recording moisture tension at the drier end of the 'available' range, where tensiometers are not suitable.

The vital information of when a plant should be watered if its growth is not to suffer, must be gained by experiments in which comparable plants are grown under different, definable, and reproducible water regimes. Techniques for such studies have been worked out; they include one, based on the use of soil moisture tensiometers, which has given good results over a number of years and has helped to elucidate the relationships between several species and their water supply [8] (figures 1–4).

In each regime a predetermined moisture tension is chosen, beyond which the soil is not allowed to dry at any depth or at any time. Since this indicates the maximum degree of dryness, it follows that most of the soil will dry out less, and the moisture content in areas where there are few roots will change little between one irrigation and the next (figure 7). An essential part of the technique is the assessment of effects of different water regimes on growth as well as on final yield, since the latter is too insensitive an indicator and may not reveal variations in the effects of moisture on growth at different stages in the life cycle.

Using such techniques it is possible to study the relationship between the growth of a plant and its water supplies. The most straightforward relationship occurs in the case of annual crops which are sown *in situ* or planted out as small plants. Experiments with young plants of lettuce (*Lactuca sativa* Linn.) or tomatoes (*Lycopersicum esculentum* Mill.), set out in beds of soil at field capacity, have shown that, as would be expected, the area immediately around each plant soon starts to dry out as the first roots extract moisture. However, roots are meanwhile growing steadily, both vertically and horizontally, into new areas of soil which are still at field capacity. Each root, as it grows

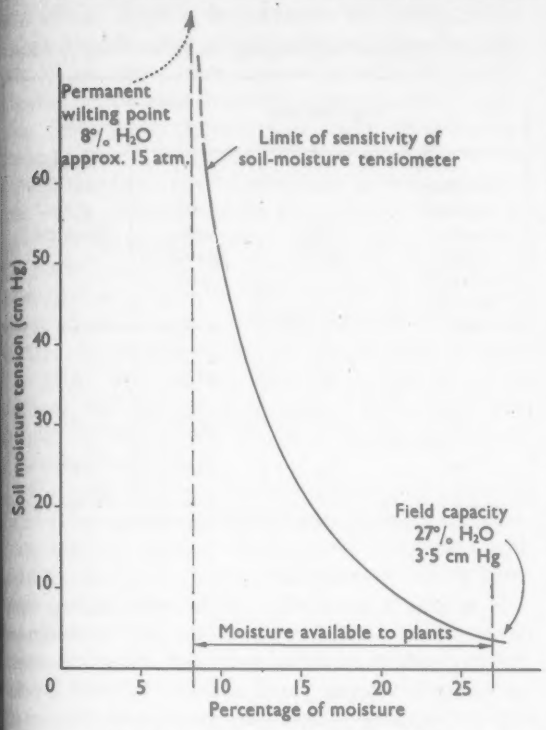

FIGURE 5 – *Soil moisture characteristic curve for a coarse sandy loam soil (Sutton Bonington).*

develops a system of root hairs which enables it to extract water from a cylinder of soil around itself. Thus the young plant has an increasing number of roots which are rapidly reaching out into new soil containing ample supplies of moisture, even though the soil around the base of the plant is soon depleted of most of the available water.

During this phase in the establishment of a plant, when roots are still growing strongly into damp soil, growth seems to be little affected by high moisture tensions in the shallower layers. Table I shows results in one of a number of experiments with lettuce (A. M. Majmudar); similar results have been obtained with young tomato plants (P. J. Salter and A. E. Moorat). It seems that these plants can make optimal growth provided that part of their root systems is in contact with moisture at low tension, even though other parts of the same root systems are in much drier soil (figure 6). Plants respond little to irrigation water applied during this phase.

However, by the time the whole available soil has been occupied by the roots of a short-term crop the rate of new root-growth is probably slowing down, and the resources of the plant are being

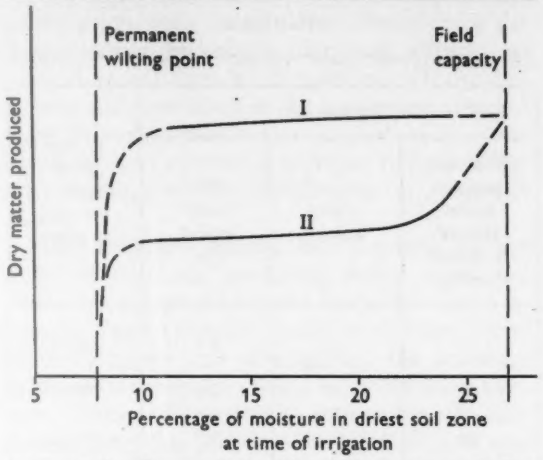

FIGURE 6 – *Curves relating the relative response of plants to the degree of dryness allowed to develop in the zone of maximum rooting (i.e. the driest layer of soil) before irrigation. Curve I: While roots are still growing into new areas of moist soil (lettuce and tomatoes). Curve II: When the whole available rooting zone has been occupied by roots (tomatoes).*

diverted to the production of fruits or storage organs. By this time, when fewer roots are elongating rapidly, the plant may respond quite differently to soil moisture. Experiments with tomatoes in the fruiting phase (P. J. Salter) have shown that the rate of both vegetative growth and fruit production falls off when high moisture tensions are allowed to develop between irrigations. Indeed, growth may then be retarded by levels of moisture tensions that would have little effect on growth at an earlier stage in the life cycle, and in mature tomato plants it seems that optimal growth and yield are possible only if the soil is maintained in a relatively wet condition, virtually at field capacity, by frequent light irrigations (table II). It must be emphasized that this response is not to total quantity of water applied but to frequency of application. Water applied little and often produces more vigorous growth than less frequent but heavier applications of the same total volume of water.

With perennial crops the situation is still less straightforward than with annuals, since a plant may start the growing season with a well established root system that already occupies most of the available soil. In such cases there is no considerable new volume of damp soil into which roots can grow in search of water, and the plants may react more sharply than newly planted crops to rising moisture tension, but this type of relationship has not yet been fully worked out.

TABLE I

Effects of different water regimes on Cheshunt 5b lettuces

Irrigation data			Average fresh weight (g) per head (48 plants)
Maximum moisture tension allowed to develop (cm Hg)	Times watered	Total water applied (cm)	
5	5	4·2	193·0
9	4	5·4	192·5
20	2	3·8	194·5
60	0	nil	197·3

Differences in yield are not significant.

TABLE II

Effects of different water regimes on Ailsa Craig tomatoes

Irrigation data			Average yield (kg) of fruit (50 plants)
Maximum moisture tension allowed to develop (cm Hg)	Times watered	Total water applied (cm)	
7	88	42·2	4·7
15	11	46·3	3·9
30	9	45·0	3·6

Differences in yield are significant.

TOTAL SOIL-MOISTURE STRESS

Another aspect of the plant-moisture relationship is intimately linked with moisture tension. The ease with which a plant can extract water from the soil depends on the 'total soil-moisture stress' [9], which is the sum of the forces concerned in the moisture tension and the osmotic pressure of the soil solution. The latter component, depending on the amount of soluble salts dissolved in the soil water, is usually negligible in damp soils of high rainfall regions, where salts are readily leached from the soil by the excess moisture that passes through the soil to drainage. It can, however, become an important factor in low rainfall areas, where salts are not washed out, or in non-saline soils that are allowed to dry out. The total amount of soluble salts in a soil does not vary as the soil dries out, but the concentration of the solution rapidly increases. Thus both the moisture tension and the osmotic pressure components of the total soil-moisture stress increase rapidly in a drying soil.

Salts tend to accumulate in soils under irrigation in arid zones, and this factor has to be taken into account in deciding irrigation practices. The difficulty can to some extent be overcome by skilful control of the timing and amounts of irrigation. For instance, the results of unpublished work with tomatoes (D. W. T. Clay) have shown that reasonable yields can be produced, in soils containing surprisingly high burdens of soluble salts, provided the soil moisture tension is maintained at a low figure by frequent light irrigations.

CONTROL OF IRRIGATION

How can a knowledge of the relationship between plants and soil moisture be used to increase the output from world agriculture? Huge schemes are being developed for the control of river levels and the tapping of new sources of water that can be distributed in an orderly way for irrigation, but unless the three questions posed at the beginning of this article are answered correctly on a field-to-field basis the water will not be used to

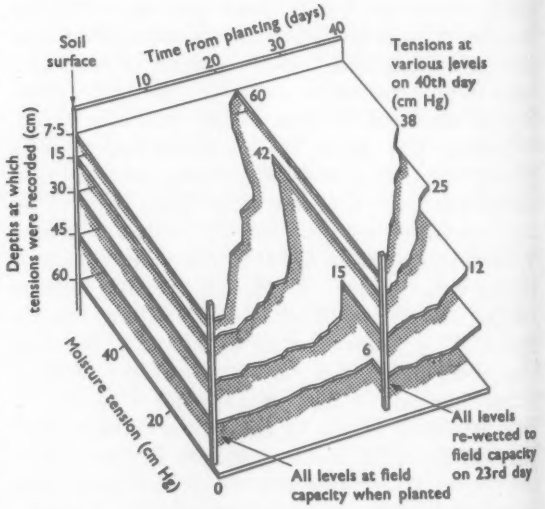

FIGURE 7 – *Model showing moisture tensions recorded at various levels in a block of soil which was being gradually occupied by the roots of a lettuce crop planted on the first day and harvested on the fortieth. There were few roots at the lowest levels.*

best effect. Application of water too early, before plants need it, may actually depress growth. The use of too much can depress growth by water-logging or causing wasteful losses into drainage. Too frequent irrigation can cause unnecessary damage to soil structure. Failure to apply water as soon as plants need it may lead to loss of growth and yield, even though the crop does not appear to be suffering from drought. Thus the use of water too early, too late, too often, too infrequently, too liberally, or in insufficient quantity can all have the effect of reducing the yield per unit volume of water. In the last resort, the effectiveness of even the most brilliant schemes of large-scale river control will depend on the policy followed in the details of the supply of water to the individual consumer—the plant.

The most effective distribution can be planned only from a detailed knowledge of the particular crop and its responses to the moisture tension and osmotic pressure of the soil solution, which may vary at different stages in the development of the root system. Perusal of the literature of irrigation research leaves one dissatisfied with much of the work, for it has been based on techniques too insensitive to reveal the details of the dynamic and complex relationships between plant, soil, moisture, and salts. Excellent work has been done on these relationships for some crops, notably those, like cotton and sugar, which are important in world trade and have well developed research organizations. There is, however, a lack of information on many other crop plants, especially those which are grown on a small scale for local consumption, even though these often provide the staple foods of the peoples concerned. There certainly does not seem to be sufficient information at present about many of the important irrigated crops to ensure that water is used to the best advantage and to serve as a proper basis for effective planning of the distribution of irrigation water.

Many irrigation systems are, of course, already highly efficient and producing heavy yields, but others are not producing the crops that could be expected from a given expenditure of water. There seems to be no way of acquiring the necessary information except by critical experiments on each crop. These will, no doubt, confirm the efficiency of some irrigation practices but in other cases may well show that heavier yields could be obtained at no extra cost by a different system of management.

The need for more experimental work is urgent if full use is to be made of the water supplies already available and those to be developed in the new plans for river control. Its aim must be to show how water can be applied at just the right time, in the right amounts, and in the right way, thus ensuring that irrigated crops make the greatest possible contribution to feeding the people of the world.

ACKNOWLEDGMENT

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The molecular basis of heredity

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Nucleic acids play an essential role in genetic processes, and chemical investigations of their structure have progressed sufficiently for general formulae to be proposed for them. Progress in these two fields is here reviewed, and it is concluded that although the facts of heredity cannot yet be completely explained in terms of molecular structure the gap between molecular and cytological levels of organization is not unbridgeable.

It is well established that chromosomes carry the genes that are the units of heredity. The genic material has been examined, and deoxyribonucleoprotein, the main constituent of chromosomes, has been studied closely. The investigations have been fruitful, and it now seems agreed that this nucleoprotein is significant in genetic processes and that the nucleic acid is particularly important.

Proteins are frequently considered to be the most important substances in living matter, but it is now clear that the nucleic acids must rank at least as their equal. A combination of cytological, chemical, and genetical experiments has led to recognition of the importance of nucleic acids in hereditary processes [1]. Some of the results of these experiments will be described briefly here, but in this article a comprehensive account of all the biological work is neither feasible nor appropriate, and our main object is an attempt to correlate the biological function of nucleic acids with knowledge of the structure of their molecules.

NUCLEIC ACIDS IN HEREDITY

The suggestion that deoxyribonucleic acid (DNA) is a genetically active material is supported by its localization in cells: cytochemical experiments have shown DNA to be located in the chromosomes, the cellular structures that carry the genes. It is recognized that chromosomes have other constituents, especially histones and other proteins, but this does not invalidate the above statement. Quantitative cytochemical measurements of DNA distribution reinforce the proposal of a genic function for it. It has been demonstrated [2] that the amount of DNA is essentially constant in the diploid somatic nuclei of various tissues within a species, and is present in half-quantities in the haploid sperm cells. On the other hand, the various proteins of the nucleus do not appear to have the distribution expected for genic material.

The discovery of the biological phenomenon of 'transformation', and of the nature of the transforming principles, afforded the first possibility of a chemical approach to the problem of heredity. The initial discovery did not attract much attention. In 1928 F. Griffith [3] reported that from mice injected with living non-encapsulated rough-colony type (R) Pneumococci mixed with heat-killed encapsulated smooth (S) variants it was possible to recover living (S) Pneumococci. Once the new feature (production of the capsule of specific type) was established, it was retained and reproduced in subsequent generations, as if a new gene had been added to the genetical make-up of the receptor cells. When killed by heat, the transformed cells would themselves induce transformation of R cells in the same way as the original S cells did. The conversion could be brought about in an R pneumococcal strain which was never observed to change or mutate spontaneously into the smooth type or any other. Although the experiments were confirmed by other workers, doubts persisted, and it was contended that the seemingly heat-killed preparations contained some heat-resistant bacterial forms, and that a 'revival' of the S cells, rather than a 'transformation' of R cells, would account for the results. Subsequently, the transformation was demonstrated *in vitro*, and soon afterwards it was found that the presence of the whole 'donor' S cell was not necessary. Transformation of R cells into the S forms was achieved with aqueous extracts of heat-killed S cells: the extracts were passed through bacterial filters before being tested for transforming activity. It was not possible to exclude a filterable virus as the responsible agent until 1944, when O. T. Avery and his collaborators [4] purified the extract and found that the 'transforming principle' had all the properties of a highly polymerized DNA. The conclusion that the isolated material was DNA was based on elementary analysis, chemical tests,

serological examination, and the observation that of all enzymes investigated only deoxyribonuclease was capable of destroying its biological activity. On heating the transforming principle, loss of biological activity commences at the same temperature (81° for 1 hour) as that at which the viscosity of the preparation begins to decrease. This behaviour towards heat is characteristic of nucleic acids, but most known proteins cannot withstand such treatment. The *p*H values at which the transforming activity begins to decrease, on both the acid and alkaline side, are the same as those at which the viscosity of DNA begins to decrease. Finally, transforming material can now be purified to the stage at which the presence of protein can be excluded on purely analytical grounds. All these results (for a full account see [5]) indicate that the transforming principle is DNA, and no conclusive evidence to the contrary has ever been presented.[1] It has since been discovered that in addition to capsule formation a number of other characters in Pneumococci are transformable. Reproducible transformations are known only in bacteria, however, and the phenomenon has not been observed in more differentiated organisms.

It is interesting to speculate whether an active DNA preparation made from many presumably identical cells represents a single chemical species or is a mixture. Although a donor may be able to transform an acceptor strain in respect of several different characters, in general each of the transformed cells is altered only in respect of one character at a time. The preparation of the transforming principle thus behaves like a mixture of different transforming particles. Doubly transformed cells occur as rarely as predicted from the probability of two independent particles entering the same cell. For this reason it is usually assumed that the 'markers' must be present on different molecules: as will be described later, the structure of DNA is capable of sufficient variation to account for this.

To summarize, there are many features of the phenomenon of transformation which are not understood, but the transforming principles do appear to be hereditary determinants, since they induce specific inheritable characteristics and initiate their own replication. These principles have been extracted from cells and identified as DNA by a variety of accepted techniques. They can be examined by the methods, suitably modified, developed to investigate the physical chemistry of nucleic acids and they can be chemically changed *in vitro*; after reintroduction into the cell the relationship between structural change and biological function can be studied. It is therefore clear that the application of chemical methods to at least one facet of heredity is possible.

Investigation of infections of *E. coli* with bacteriophages of the type T has yielded extremely interesting results about the production of new specific forms of DNA within a cell already organized for the biosynthesis of the host's own type of DNA, and provides another pointer to the genetic significance of this nucleic acid. The T-coliphages which lyse the host bacterium *E. coli* are principally composed of protein (about 60 per cent) and DNA (about 40 per cent), together with a small amount of lipid. It seems that the DNA is mechanically, rather than chemically, confined by the protein, which exists largely as a membrane surrounding a mass of free or loosely bound DNA. Although this is not a complete description of T-phage structure, it makes it possible to distinguish the functions of the protein and DNA components respectively. When coliphage is added to *E. coli* cells in a suitable environment, the phage particles are rapidly adsorbed on the bacteria. Adsorption soon becomes irreversible and the bacterium is killed. After a latent period, the cell lyses and a large number of new phage particles are liberated. A. D. Hershey and M. Chase [6] have demonstrated that the DNA plays a major role in this process. By means of isotopic tracers it was found that the DNA of two other infecting phages (T_2 and T_6) enters into the infected cell, while the protein component remains outside.

It thus appears that the DNA of the phage is capable of carrying forward the process of infection and that the protein is not required after the DNA has been introduced into a host cell. In the subsequent stages of T-phage reproduction, quantities of phage-protein membranes and phage DNA are synthesized in the infected cell. These are specific macromolecular materials, different from any of the components of the non-infected host. It is generally assumed that such species-specific materials are produced under the influence of specific genetic determinants, in this

[1] For successful transformation of Pneumococci other factors besides the transforming principle need to be present. These agents are believed to produce 'sensitization' of receptor cells, a temporary change of unknown nature. For transformations of *Haemophilus influenzae* and *Neisseria meningitides*, however, no need for additional factors (other than those in the medium) could be established, and so it appears that these factors are not primarily responsible for the transformation.

case the DNA of the phage. Although the detailed biochemical processes have not been worked out, it seems that the DNA of an infecting T-coliphage controls the nucleic acid and protein metabolism of the host cell much as if it were a genetic entity dominating the host genes.

In the present state of knowledge, it would be unwise to conclude from observations such as the above that chromosomal DNA alone carries the specific genetic determinants in higher organisms. There are indications that other factors may then be involved, but equally there are observations which point to *in vivo* genetic properties attributable to DNA. In this respect the following experiment may be mentioned. Intact cells in fungi and corn were irradiated with ultra-violet light, and the wavelength most effective for producing genic mutations was found to be the same as that at which the absorption of the ultra-violet light by DNA was greatest. Some evidence of the chemical nature of genes can be found in the effects of certain mutagenic agents like the nitrogen and sulphur mustards, to which the nucleic acids are highly susceptible: X-rays likewise have disruptive effects on DNA. It may be a coincidence that the cytogenetic action of the sulphur and nitrogen mustards and of X-rays is to produce chromosome breaks and other effects, but it is an attractive hypothesis to relate the sensitivity of DNA towards these agents with chromosomal changes: this theme will be developed more fully later.

In nature, there are two types of nucleic acid, namely deoxyribonucleic acid (DNA) and ribonucleic acid (RNA). So far, this article has been limited to DNA, but investigations on RNA are also important. Description of these must, however, be limited to a brief mention of some results concerning virus multiplication. In common with other self-reproducing or protein-synthesizing units, plant and animal viruses are nucleoproteins. Although animal viruses contain RNA or DNA or both, the plant viruses contain RNA exclusively: the RNA content ranges from 6 per cent in tobacco mosaic virus up to 35 per cent in turnip yellow mosaic virus. The fact that substances as relatively simple as ribonucleoproteins are able to reproduce themselves, and are thus endowed with genetic continuity, is of the utmost importance. Moreover, from work with turnip yellow mosaic virus it was concluded that there is some evidence that the nucleic acid is in fact the substance controlling virus multiplication [7]. Experiments with tobacco mosaic virus showed first that the protein could be changed chemically without affecting the activity of the virus, and then that part of the protein could be removed without destroying the activity. Very recently A. Gierer and G. Schramm [8] have obtained evidence that after complete removal of the protein from the virus nucleoprotein the RNA alone is still infectious and appears to maintain the genotype.

Many published papers lead to the conclusion that RNA plays an essential role in protein synthesis in cells of all types. Little is known of the precise relationship between the DNA of the nucleus, which remains relatively constant, and the RNA of the cytoplasm, which appears to be more directly involved in protein synthesis. Recently, it has been claimed [9] that direct evidence has been obtained that cytoplasmic RNA or its precursor is synthesized in the nucleus and transmitted to the cytoplasm. It is possible to speculate on the means by which the specific nucleotide pattern preserved from one generation to the next in the DNA can be transmitted to the RNA to be operative in protein synthesis, but in the absence of precise knowledge of the molecular configurations of RNA and of nucleoproteins such speculations are of doubtful value.

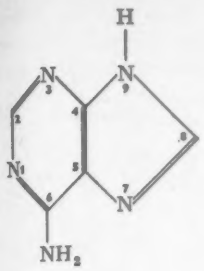
STRUCTURE OF NUCLEIC ACIDS

The composition of nucleic acids has been deduced from examination of hydrolysates obtained both chemically and enzymically, and it appears that the successive stages of degradation are as follows:

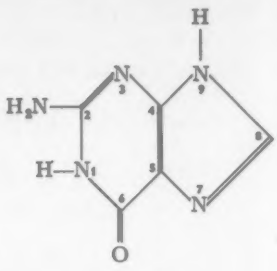
Nucleic acid → simple nucleotides
→ nucleosides + phosphoric acid
→ purine and pyrimidine bases + sugar

The purine bases obtained from DNA are adenine (I) and guanine (II), and the pyrimidine bases are cytosine (III) and thymine (IV). Some samples of DNA contain small amounts of 5-methylcytosine, but the occurrence of this is limited, as is that of 5-hydroxymethylcytosine. The sugar is 2-deoxy-D-ribose (V)[1], present in its furanose (5-membered ring) form. The bases are glycosidically joined to the sugar at C(1′), and the linkage is of the β-type. Union occurs at position 9 of the purine bases and at position 3 of the pyrimidine molecules. The sugar-base units are the nucleosides. The simple nucleotides isolated from DNA are nucleosides esterified by phosphoric acid at the primary hydroxyl position C(5′) in the sugar

[1] The prime is added to the numbers indicating the carbon atoms in the sugar ring when the sugar is linked to a purine or pyrimidine ring: the numbering of the latter is as shown in formulae (I)–(IV).



I



II

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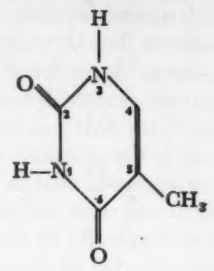
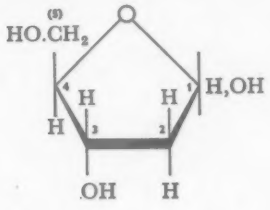
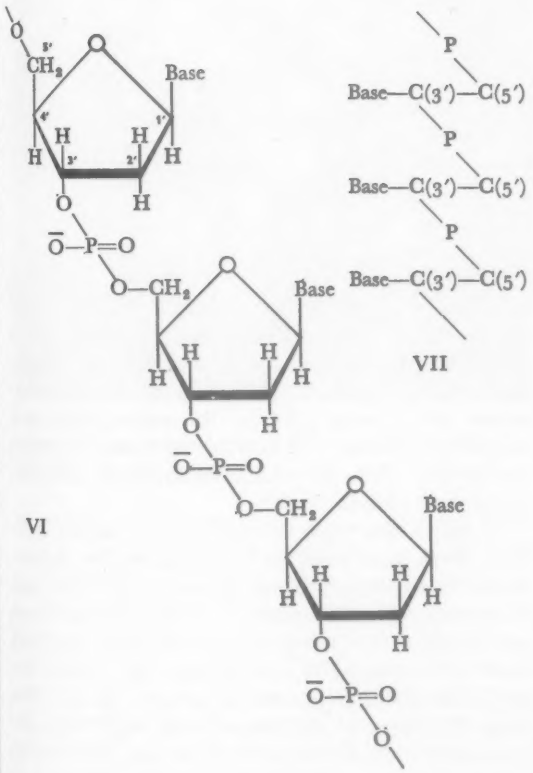


IV

moiety. Acid hydrolysis of DNA produces some pyrimidine nucleoside-3′:5′-diphosphates, which indicates participation in the nucleic acid mole-



V



VI

VII

cule of the C(3′) position in the sugar. The formulation of DNA which most satisfactorily accords with all the evidence is a linear unbranched polynucleotide chain (VI, abbreviated as VII) with a recurring 3′:5′-internucleotide linkage leading to a molecule of very high molecular weight (5–8 millions).

The structure proposed poses two further problems, namely the sequence of bases along the polynucleotide chain and the amount of each base in the nucleic acid: answers to both might be significant in genetics. So far, the determination of nucleotide sequence has barely begun, but much is known concerning the total base composition of various forms of DNA.

Originally it was thought that the bases were present in equivalent amounts, but painstaking analysis of a large number of samples of DNA from a variety of sources has disproved this. The following relationships have emerged from this work:

(*a*) Two main types of DNA can be distinguished: the AT type in which the adenine-thymine content outweighs the amount of guanine-cytosine, and the GC type, which occurs mainly in micro-organisms, where the reverse is true.

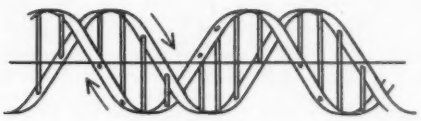
(*b*) The sum of the purine nucleotides equals the sum of the pyrimidine nucleotides.

(*c*) The molar ratio of adenine to thymine equals 1, as does the molar ratio of guanine to cytosine (if the DNA contains 5-methylcytosine, the molar ratio of guanine to the sum of cytosine and its 5-methyl derivative equals 1).

(*d*) The number of 6-amino groups equals the number of 6-keto groups.

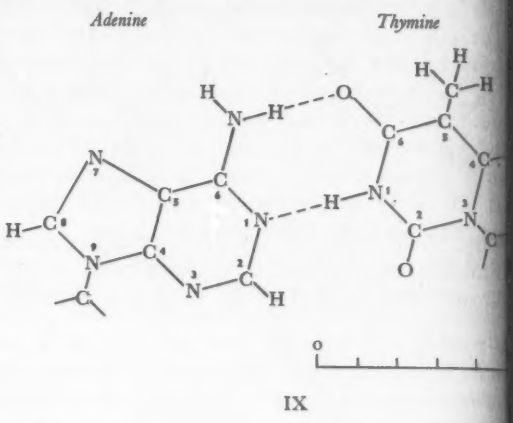
The significance of these relationships becomes apparent when they are considered in conjunction with the elegant X-ray studies of M. H. F. Wilkins, A. R. Stokes, and H. E. Wilson [10]. DNA from a variety of sources such as calf thymus gland, *E. coli*,

and mouse sarcoma give X-ray diagrams which indicate that they are all constituted on the same pattern. A model of DNA which accommodates the chemical evidence and agrees in essentials with the X-ray data has been developed [10, 11] on the basis of the postulate of specific base pairs. Briefly, it is supposed that in DNA there are in the structural unit two polynucleotide chains which are wound spirally in the same way round the same axis but run in opposite directions. The helical nucleic acid molecule has in the solid state two main configurations: the very compressed, highly crystalline structure (A) and the slightly more extended helix (B), the structure of which is often paracrystalline. Here we are concerned only with the (B) structure. The pitch of the helix is 34 Å and there are 10 nucleotide residues per turn of each strand. Both sugar-phosphate chains follow a right-hand helix and are held together by hydrogen bonds, involving the base residues, to form a double helix of diameter 18 Å. This is shown pictorially in VIII; figure 1 is a photograph of the

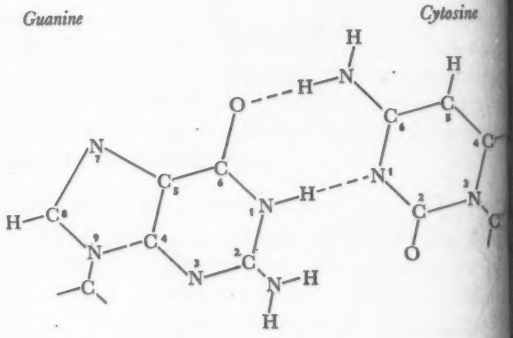


VIII[1]

double-helical model which has been constructed at King's College, London. There is considerable evidence [12] that the double helix persists as the water content of the DNA increases until the DNA is in solution. Since the phosphate groups are on the outside of the helices, cations have easy access to them; the purine and pyrimidine bases, on the other hand, lie inside the helices and perpendicular to the long axis. A novel feature of the structure is that specific base-pairing is postulated. Examination of models suggests that only the adenine-thymine and guanine-cytosine pairs can bond together and at the same time fit into the structure, a conclusion supported by the analytical data mentioned earlier. The hydrogen bonds lead to the formation of the structures shown in (IX) and (X). This base-pairing accounts well for the observed base ratios, and yet permits the variation of base composition which is found experimentally. It will be noted that in this structure the strands are complementary, since the nucleotide sequence on one strand automatically fixes that on the other. By the impo tant discovery of DNA fractionation it has be shown that the DNA molecules of one species e



IX



X

hibit demonstrable differences not only in size b also in the proportions of individual purines a pyrimidines. The compositions of whole DN preparations recorded in the literature are ther fore averages and not those of individual mol cules. Here is support for the assumption th the DNA of each cell consists of many differe molecules, each of which determines differe hereditary characteristics.

In RNA the sugar is D-ribose (XI is the fur nose form numbered as V) to which the hetero cyclic bases are united by glycosidic linkage wit β-stereochemical disposition. The purine bas are the same as occur in DNA: cytosine is found i both DNA and RNA, but thymine does not occ in RNA, being replaced by uracil (XII). Th sites of linkage of the bases to the sugar are th same as in DNA, i.e. at N(9) of the purines an at N(3) of the pyrimidines. D. M. Brown an A. R. Todd [13] have postulated a recurri

[1] The two ribbons symbolize the two phosphate-sugar chains and the vertical rods the pairs of bases holding the chains together. The horizontal line is the fibre axis.

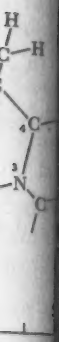
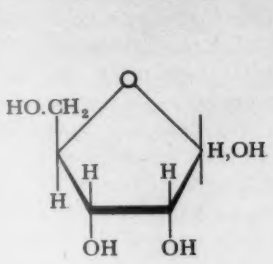
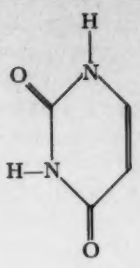


FIGURE 1 – *Model of the paracrystalline B form of DNA showing* 16 *nucleotide pairs. The model (dimensions approx.* 109 *cm* × 51 *cm) is constructed on the scale* 2 *cm* ≡ 1 Å.

3′:5′-internucleotidic linkage for the main RNA chain, as shown diagrammatically in XIII. The nucleic acid is shown unbranched: as yet there is no satisfactory evidence for branching in natural RNA, and recent titration evidence suggests the contrary [17]. Todd [14] has pointed out that in theory at least two types of polynucleotide are possible, one bearing the terminal phosphate at C(3′) in the nucleoside residue and the other with the terminal phosphate at C(5′). The 'monomers' for the first type would be nucleoside-3′-phosphates, and for the second type nucleoside-5′-phosphates. End-group assays on RNA have shown examples of both types, but this is hardly decisive, since any degradation of an acid of the latter type would inevitably yield materials with end-groups corresponding to the former

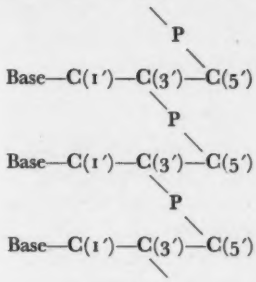


XI



XII

A stepwise degradation method for determining polynucleotide sequence in RNA has been proposed. It has been used successfully with small oligonucleotides, but its application to the nucleic



XIII

acids must await the preparation of these materials in a truly homogeneous condition. Determinations of base composition in RNA are less revealing than with DNA, although it appears that the amount of 6-keto (guanine and uracil) groups equals the amount of 6-amino (adenine and cytosine) groups [15].

Likewise, the macromolecular structure of RNA is less well established than is that of DNA. The molecular weight of RNA, as isolated, is very much less than is found for DNA. So far, the X-ray patterns from various samples of RNA are identical, but the pictures are poor and hard to interpret. Helical structures for RNA have been tentatively proposed. When solutions of the sodium salts of the enzymatically synthesized nucleotide polymers—polyadenylic acid and polyuridylic acid—are mixed, there is a rapid increase in viscosity. From the viscous solution tough glassy fibres can be drawn, and these produce a

well orientated X-ray diffraction pattern with a distribution of intensity characteristic of a helix [16]. These results are taken to mean that the molecule is a two-stranded helix containing one strand of polyadenylic acid and one of polyuridylic acid. The bases, adenine and uracil, link with each other through two hydrogen bonds, in the same way as postulated for adenine and thymine in DNA, with the base pairs stacked above each other roughly perpendicular to the fibre axis. These results show for the first time that it is possible for the backbone of the RNA molecule to assume a configuration not unlike that in DNA, with complementary pairing of the bases. This implies that there may exist a form of the RNA molecule similar to that of DNA, and that this could be the form in which RNA carries out its supposed molecular duplication in the plant and smaller animal viruses.

Recently R. A. Cox and collaborators [17] have obtained electrometric titration data from which it was inferred that hydrogen bonding occurs in a bacterial and a yeast RNA. Whether or not these hydrogen bonds link the same groups as in DNA cannot yet be determined.

NUCLEOPROTEINS

The foregoing structures for the nucleic acids have been derived from work on material which had been separated from the protein with which they are combined *in vivo*.

Several lines of evidence indicate that the double helical DNA structure is present also in nucleoproteins and in relatively intact biological structures such as the heads of fish sperm [18]. The simplest nucleoprotein is that of fish sperm, since in this the protein is composed chiefly of arginine residues and is of low molecular weight (4000–10 000) [19].

X-ray diffraction studies [20] suggest that a fully extended polyarginine chain is wound round the shallower of the two grooves of the DNA double helix, and other physicochemical evidence suggests that it is anchored to it by purely electrostatic forces between the positive arginine groups and negative phosphate groups. It was suggested [20] that since the non-basic amino acid residues (those with uncharged side chains) occur in pairs in protamines, they could possibly be accommodated as loops in the polyarginine chains, perhaps held by interaction with the DNA base rings. The suggestion could possibly apply also when histones are involved instead of protamines, since the former contain a higher proportion of uncharged side chains. This nucleoprotamine structure explains the long-observed equivalence of the spacing (3·4 Å) between nucleotides in DNA and between amino acids in the fully extended β-form of polypeptides. Optical evidence that the proteins in nucleoproteins are in the β-form has also been obtained [18]. The nucleoprotamine structure affords no obvious explanation of DNA specificity towards proteins, unless this lies in the suggestion about the looped amino acid side chains and their possible interaction with the base rings.

The ribonucleoproteins that have received most attention are the plant viruses. X-ray diffraction studies have shown [21] that the phosphate–sugar backbone chain of the RNA in tobacco mosaic virus is deeply embedded in the virus protein, which is made up of sub-units helically arranged.

BIOLOGICAL ASPECTS

Any theory which attempts to explain the facts of heredity in terms of molecular structure must eventually account for self-duplication, for specificity, and for variation and modification of the genic material. The structure described above for DNA has certain implications, some or all of which may prove to be important to its biological function. Firstly, the double helical structure allows the possibility of self-duplication. In the schematic representation (figure 2), if the sequence I is CTAGGTG[1] . . . and II is the complementary sequence GATCCAC . . ., then if I and II can be separated in some way and acquire new partners in two new double helices, these will have the structures I—II′ and I′—II respectively, where the primes indicate new chains. The sequence of nucleotide pairs of the original molecule I—II has therefore reproduced itself in its 'progeny', I—II′ and I′—II. Since it is not possible laterally to separate two coils entwined as in the DNA structure, there has been much speculation on possible mechanisms for the replication of DNA. In most of the more plausible mechanisms it is considered that replication proceeds synchronously down the two chains without at any time requiring the existence of free single strands.

Secondly, there is the possibility of variation. Since isolated DNA contains 10^4 or more complementary nucleotide pairs there are of the order of $4^{10\,000} \simeq 10^{6000}$ possible nucleotide sequences for individual DNA molecules. The nucleotide sequence seems to be the only possible basis for the specificity of DNA molecules, but this must

[1] C = cytosine or 5-methylcytosine, T = thymine, G = guanine, and A = adenine nucleotide residues.

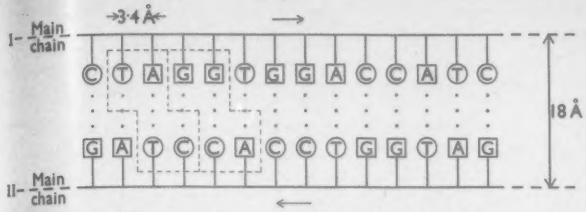


FIGURE 2 – *Diagram of two possible complementary base sequences in the double-helical deoxyribonucleate molecule.* ⊓ *Purine nucleotide unit (A = adenine residue, G = guanine residue).* ⊔ *Pyrimidine nucleotide unit (T = thymine residue, C = cytosine or 5-methylcytosine residue) . . . Hydrogen bond systems (see IX and X) cross-linking the two helical main chains, represented by continuous straight lines. Arrows show directions of the main chains. Helix diameter 18 Å; the internucleotide distance of 3·4 Å along the axis refers to the paracrystalline B form. Broken lines enclose two hypothetical 'coding' units.*

manifest itself eventually in specific proteins with particular amino-acid sequences. The question arises: 'How can the sequence of more than twenty different amino acids be guided by only four kinds of base?' To answer this P. C. Caldwell and C. N. Hinshelwood [22] suggested that the 'code' for each amino acid might consist of two adjacent nucleotide units, and G. Gamow [23], employing the double helical model, has suggested a triplet code, since there are twenty possible combinations of bases (disregarding order), taken three at a time from the four available. Figure 2 shows, enclosed in broken lines, two such groupings of three independent elements; it must be remembered that the middle pair constitutes only one independent element. Analysis of the frequency with which any one amino acid follows another in the few simple proteins for which the sequences are known, indicates that these sequences are entirely random, and it is suggested that the nucleotide triplets do not overlap.

Thirdly, we must consider the possibility of modification of the DNA molecule. Here various possibilities suggest themselves.

(*a*) As stated, the internucleotide phospho-ester linkages can be destroyed by a variety of agents, including ionizing radiations and enzymes. When single phospho-ester linkages are broken by these last two methods, it has been shown [12*c*, 24, 25] that the molecule separates into two parts only if the breaks occur at opposite, or nearly opposite, positions in the two chains (e.g. α1, α2, figure 3). If the breaks in opposite chains (e.g. α1, α4) are separated by more than two or three [25] hydrogen-bonded pairs the molecule remains intact, although its shape may change. Breaks in the same chain (e.g. α1, α3) need not cause detachment of the intervening units and are revealed only by subsequent rupture of the hydrogen bonds. The effects of sulphur and nitrogen mustards have been thought to be caused by rupture of internucleotide linkages by first forming unstable tri-esters of the phosphoric acid residues.

It is possible to find a formal similarity between the consequences of internucleotide bond rupture in DNA caused by ionizing radiations and the chromosomal changes these agents evoke. Thus if the segment produced by breaks α1–α2, α4–α5 rejoined, so that the atoms involved at α2 were then at α5 and those at α1 were at α4, there is a state of affairs formally similar to inversion within a chromosome, especially if nucleotide sequence and pattern are still identified with protein specificity and ultimately with gene action. Similarly, the double break α1–α2 would result in two fragments, which if they linked up with others would give an effect analogous to chromosomal interchange. Further, if the breaks α3 and α5 occurred in conjunction with hydrogen bond rupture (γ), as during γ-irradiation, the segment α3–α5 would be lost and the replication of this section

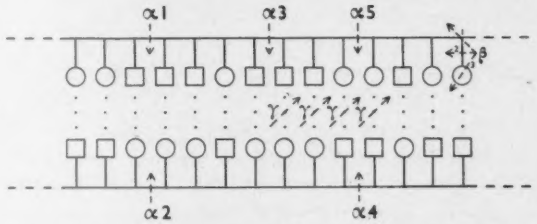


FIGURE 3 – *Possible modifications of the deoxyribonucleate molecule (depicted schematically as in figure 2).* – – → *Possible breaks.* α, *Breaks in the main-chain phospho-ester linkages.* β, *Breaks in other covalent bonds of the nucleotide units.* γ, *Rupture of the cross-linking hydrogen bonds (see IX and X).*

would be impaired: this could be part of the molecular basis for mutations. At present, however, these constitute formal analogies only, because of the disparity of scale between chromosomes and the DNA molecules.

(*b*) Other covalent bonds might be destroyed (e.g. β1, β2, β3, figure 3), but usually by treatment under conditions which are probably less important biologically.

(*c*) The rupture of cross-linking hydrogen bonds (γ, figure 3), usually called 'denaturation' because it leads to permanent loss of the helical configuration, can be caused by ultrasonic irradiation, by ionizing radiation, by heat, by solutions of high or low *p*H, and presumably by enzymes [25]. In the

case of heating and ionization it seems [26] that a minimum sequence of ten or more hydrogen bonds has to be ruptured before permanent denaturation occurs (as γ, figure 3). Hydrogen bond rupture is one of the first detectable effects of γ-rays [12*c*] on DNA in solution and must cause a loss of the double helical form in various sections, thereby perhaps impairing its ability to replicate.

Although these analogies between chemical and biological behaviour are encouraging, it is not possible to go any further at present because of our ignorance concerning the arrangement of the DNA molecules in the chromosomes [18]. The diameter of a single DNA molecule is 18 Å, and that of the simplest nucleoprotein is only slightly more than this [20], whereas the next nearest units of chromosome architecture seem to be the particles (4000 Å long by 400 Å wide) isolated by D. Mazia [27], or the 'microfibrils' of 100–200 Å diameter observed in the electron microscope [18]. Such units could contain many DNA molecules: Wilkins [28] has reported X-ray evidence for a regular array in fowl erythrocyte nuclei of parallel nucleohistone molecules of 20 Å diameter and 45 Å apart. Since DNA molecules, as isolated, usually have a length along the axis of the order of 30 000 Å (for a molecular weight of about six million), which is sometimes very much greater than the largest dimensions of the biological structures from which they are derived, it has been proposed [18] that at certain points the DNA molecule can fold back on itself. This is feasible if there is an occasional internucleotide break (α).

The double helical structure of the DNA molecule can now perhaps be identified with the 'molecular spirals' long postulated as the basis of the visible chromosome spirals [29]. S. Benzer [30] has recently shown that it is possible to obtain recombination between very closely linked sites on the genetical chromosome of a bacteriophage which, if the physical chromosome were DNA, would correspond to a separation of only about a dozen nucleotides, and thus the gulf between the molecular and cytological levels of organization may eventually be bridged.

ACKNOWLEDGMENTS

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Plant virus diseases and their identification

R. MARKHAM

While it is difficult to assess the relative economic importance of the various types of disease agents in plants, there is little doubt that the attention paid to the viruses is much less than it should be. This is because they are rather difficult to handle experimentally, and the symptoms which they produce in plants are not familiar even to many plant pathologists, and so are often overlooked or thought to be due to mineral deficiencies or fungal diseases.

The range of plants susceptible to virus infection is very great, and one may expect to find at least one virus disease of any flowering plant, though oddly enough the conifers and lower plants do not appear to be susceptible to virus diseases. The number of viruses affecting plants is also great; the known number is now in the hundreds and increasing all the time. Many viruses are extremely catholic in their choice of host, infecting species of both monocotyledons and dicotyledons. Most viruses, it is true, tend to have a somewhat more restricted host range, but it is exceptional for a virus to infect only one species of plant, and this is one of the more insidious characteristics of this type of parasite. It is unusual for a plant either to recover from virus infection or to die because of it, with the result that sources of infection tend to increase in numbers, especially when the host plants are perennial and are propagated by vegetative means, as are, for example, potatoes and many garden plants.

THE NOMENCLATURE OF PLANT VIRUSES

Most plant viruses have trivial names, derived from the symptoms exhibited by the host on which the virus was originally found. The use of this type of nomenclature, based as it is on historical accident, is frequently a cause of confusion. For example, one of the more widespread and important virus diseases in Great Britain is called cucumber mosaic (figure 8), but the cucumber (*Cucumis sativus*), being a tender and exotic plant, is quite obviously incapable of being the primary host of an obligate parasite like this virus, which actually has an immense host range (figures 2, 4, 7, 9–11). This range includes many hardy perennials such as *Chrysanthemum*, *Daphne*, and *Euonymus*, from which the virus is spread by migrating aphids, the natural vectors of this disease.

An interesting example of the confusion that this type of nomenclature may cause is seen in the disease known as tobacco necrosis. This disease was originally observed many years ago in Cambridge, when tobacco plants (*Nicotiana tabacum*) which were being used for experimental purposes were inoculated with sap pressed out from their own roots. A characteristic disease developed (figure 13), and the virus was found to cause similar symptoms on a large number of plants, in none of which was it able to produce symptoms other than local ones. This virus, or, as it was later found to be, group of viruses, was studied for years as an academic curiosity. Some seven years ago, however, it was found to be causing a serious disease of french beans (*Phaseolus vulgaris*) in Holland, from which country tulips (*Tulipa* sp.) also having this virus have been imported into Britain (figure 14). It is also now frequently found in plants of *Primula obconica*, which have become infected by being raised in contaminated soil. This virus is unusual in being transmitted in this way, and the original infections presumably arose from inadequately sterilized potting-soil.

PLANT VIRUS SYMPTOMS

Flower 'breaking'. The most obvious, and certainly the least unattractive, symptoms caused by viruses are the flower breaks. In these, virus infection causes characteristic alteration of the pigmentation of the flower petals. The reddish and bluish colours of flowers are due to anthocyanin pigments, and most flower breaks affect these pigments. The best-known example of this is to be found in tulips, which are subject to a specific virus which causes the flower colour to break (figure 1). In tulips, as in other plants, such as the wallflower (*Cheiranthus*), a blood-red or orange-red colour is usually due to an anthocyanin pigment superimposed on carotenoid pigments, and it is unusual for the latter to be affected. In this case one gets a break with a yellow background, such as is caused in the wallflower (figure 3) by the

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FIGURE 1 – *Tulips showing flower break caused by the specific tulip breaking virus.*

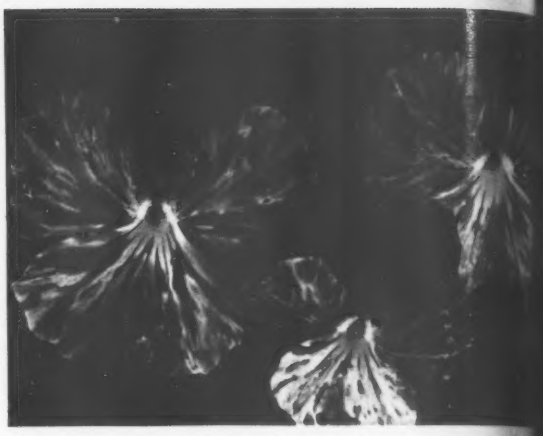

FIGURE 2 – Viola tricolor *showing a flower break due to cu mosaic virus.*

FIGURE 3 – *Wallflowers infected with cabbage black ringspot virus. Healthy flowers are shown on right.*

FIGURE 4 – *Flower break in* Campanula isophylla *infecte cucumber mosaic and another virus.*

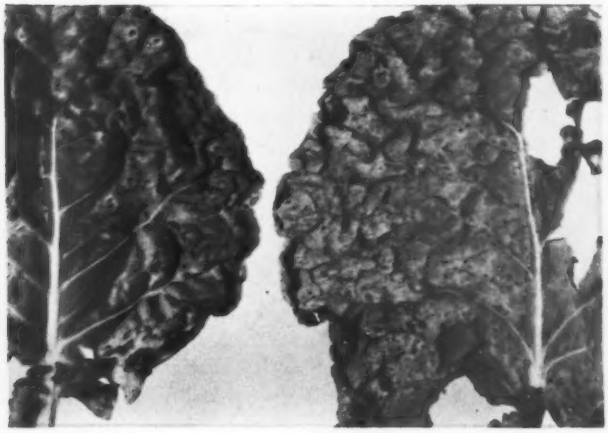

FIGURE 5 – *Brussels sprouts plants infected with cabbage black ringspot virus.*

FIGURE 6 – *Flower break of sweet pea caused by the pea virus.*

URE 7 – *A flower break, frequently found* Gladiolus, *due to cucumber mosaic virus.*

FIGURE 8 – *Cucumber mosaic virus on cucumber.*

FIGURE 9 – *Larkspur, showing flower breaking caused by cucumber mosaic virus.*

URE 10 – *Symptoms of cucumber mosaic* on tomato. *Note the reduction of leaf* ina *and the distortion of the flowers.*

FIGURE 11 – *Dahlia showing symptoms of infection with cucumber mosaic virus.*

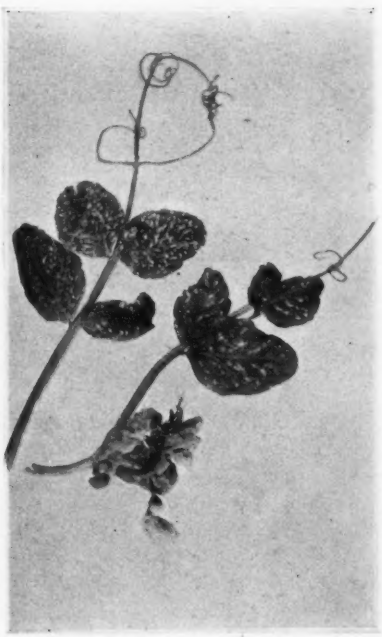

FIGURE 12 – *Pea mosaic virus. This is one of the few seed-transmitted virus diseases.*

FIGURE 13 – *Lesions of tobacco necrosis virus on tobacco.*

FIGURE 14 – *Necrotic symptoms on tulip, now known to be due to tobacco necrosis virus.*

FIGURE 15 – *Sugar beet yellow virus, economically a very important disease of sugar beet.*

FIGURE 16 – *Tumour or enation on the underside of a cucumber leaf, caused by tomato blackring virus.*

GURE 17 – *Tomato spotted wilt virus tomato, showing ringspotting and nzing.*

FIGURE 18 – *A ring-shaped lesion on a tomato fruit due to the tomato spotted wilt virus.*

FIGURE 19 – *Underside of a potato leaf, showing typical primary symptoms of potato Y virus. These are often mistaken for those of blight* (*figure* 20).

GURE 20 – *Potato leaf showing blight* hytophthora) *lesions.*

FIGURE 21 – *Typical symptoms of cabbage black ringspot virus on tobacco, which is used as a test plant for this virus.*

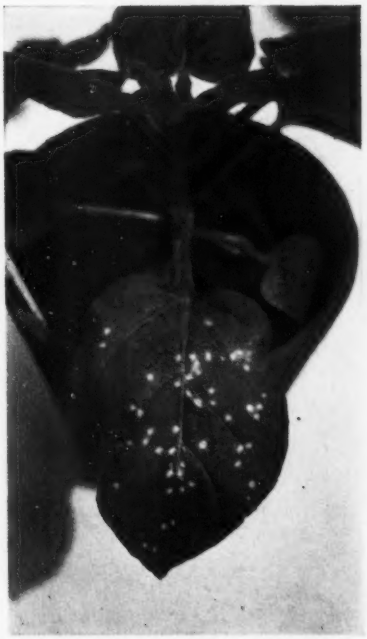

FIGURE 22 – *Local lesions of tobacco mosaic virus on* Nicotiana glutinosa. *These may be used for quantitative assay.*

FIGURE 23 – *Potato leaf-roll virus. This very severe virus infection is common in the south of England and is spread by aphids, as are many plant viruses.*

FIGURE 24 – *Curly dwarf, a disease of potato caused by c infection with potato viruses X and Y.*

FIGURE 25 – *Potato virus X on tobacco, which is one of the best test plants for diagnosing this disease. The symptoms develop about a fortnight after inoculation.*

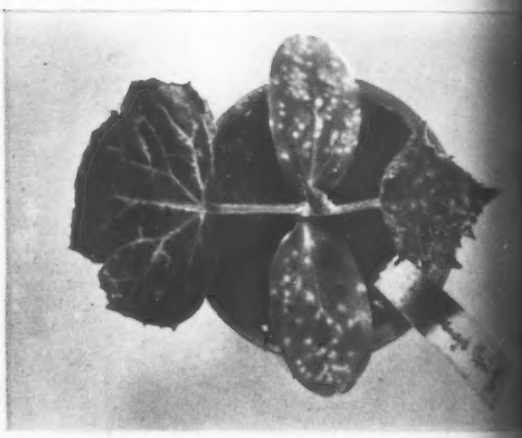

FIGURE 26 – *Local lesions and systemic mosaic of cu inoculated from a South American potato plant.*

FIGURE 27 – *Turnip yellow mosaic causing an extremely brilliant mosaic on* Brassica sinensis.

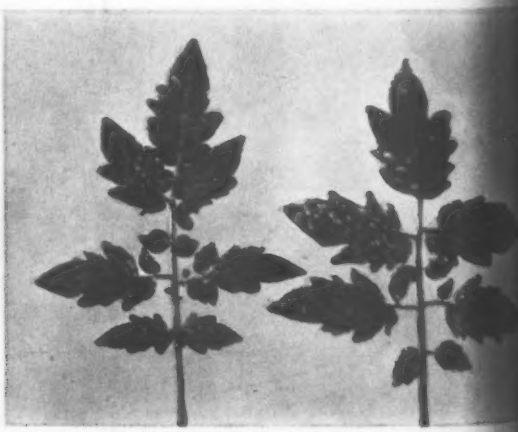

FIGURE 28 – *Aucuba mosaic of tomato. This is caused strain of the tobacco mosaic virus.*

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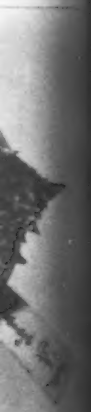

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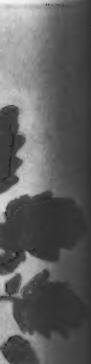

is caused

abbage black ringspot virus; this virus is very ommon in brassica crops (figure 5), in which the ymptoms might easily be taken as being due to ineral deficiency.

Occasionally, colour breaking affects only part f the anthocyanin pigmentation, and one may hen get multicolour effects as in pansy (*Viola icolor*, figure 2) and in larkspur (*Delphinium* sp. gure 9). These two colour breaks are caused by he cucumber mosaic virus, as are breaks of many ther plants, such as *Gladiolus* (figure 7), *Anemone*, tc. These quite obvious symptoms are so infre- uently recognized that the break in larkspur, for xample, has been investigated under the impres- on that it was a genetic character, while a super- cial examination of flowering plants in nurseries uggests that many 'varieties' are in fact merely ormal plants showing disease symptoms.

The physiology of flower breaking is a subject hat would well repay investigation, and it is in- resting that a virus which causes breaks in one lant will not necessarily cause them in another aving the same anthocyanin pigments. Thus cu- mber mosaic virus, although extremely common *Dahlia*, never causes its flowers to break.

Another common flower break is that of the weet pea (*Lathyrus odoratus*, figure 6), which is used by pea (or bean) mosaic virus (figure 12). his virus causes serious diseases of peas (*Pisum ativum*) and beans (*Vicia faba*), and is all the more ious because, unlike most viruses, it is quite fre- uently carried through the seed, as well as being read by aphids. Seed transmission also occurs ite commonly in the case of lettuce mosaic rus, but in most plants some kind of physio- gical barrier prevents infection of the seeds, hich thus give rise to healthy plants.

THER TYPICAL PLANT VIRUS DISEASE MPTOMS

Mosaics. One of the commonest symptoms is e mosaic, a typical example of which in *Dahlia* is own in figure 11. This particular mosaic is used by the cucumber mosaic virus. Other mosaic mptoms are shown in figures 8, 12, and 25–28. osaics are caused by variations in the chlorophyll ntent of various parts of the leaves, and may nge from a scarcely visible mottle to a brilliant riegation such as is given by dandelion (*Taraxa- n*) yellows virus and turnip yellow mosaic virus Chinese cabbage (*Brassica sinensis*), both of which ght be mistaken for genetic variations.

Malformations. While most mosaics are accom- nied by slight leaf malformations, some extreme cases are to be found. Figure 10 shows the typical symptoms of cucumber mosaic virus on the tomato, an appearance which sometimes leads growers to imagine that the leaves have been eaten away by insects. Such symptoms may also be caused by a strain of tobacco mosaic virus, and a somewhat similar effect may be produced by the accidental application of selective weedkillers.

Another type of malformation is the enation, which is a tumour of leaf tissue: a good example of this may be seen on a cucumber leaf (figure 16), due to the tomato blackring virus. An unusual feature of this virus is that it causes the formation of enations only of glasshouse cucumbers, and not of the outdoor, or ridge, varieties.

Yellowing. The symptoms of yellowing of the leaves are to be found in Britain in two important virus diseases, sugar beet yellows (figure 15) and potato leaf-roll (figure 23), and they differ from mosaics in that the lack of chlorophyll is not defined as blotches. These diseases cause damage to the vascular system of the plant, and they are characterized by the leaves becoming leathery in consistency, with a tendency to pigmentation. Potato leaf-roll is fairly characteristic but may be confused with symptoms due to injury of the stem, while sugar beet yellows is easily mistaken for symptoms of mineral deficiency.

Ringspots and necrosis. Many viruses tend to cause the formation of rings on their hosts, and a particularly characteristic ring is shown in figure 18, which shows the effect of tomato spotted wilt virus on the fruit of tomato. This virus also causes the formation of rings on a large number of plant leaves, including those of tomato (figure 17), in which it also causes the production of antho- cyanins, which make the leaves turn bronze. Other symptoms of the ringspot type are to be seen in figures 13, 21, 22, and 26, which show local symptoms on artificially inoculated leaves, and in figure 5, which shows the results of a systemic infection.

Ringspots may be purely chlorotic, but are very frequently necrotic. If the necrosis is very severe it kills the infected cells and so cuts the virus off from the healthy tissues. This is shown in figures 13 and 22. If the necrosis is less severe locally, the net effect on the plant is worse. Figure 19 shows the primary symptoms of potato Y virus on potato, which may be confused with potato blight (*Phyto- phthora*) infection (figure 20). Close examination of the underside of the leaf, however, shows that the necrosis is confined to the veins, down which it progresses, after which the leaves collapse and

hang down. Chronic infection with this virus together with the potato X virus causes an extremely severe stunting of the potato (figure 24).

METHODS OF IDENTIFICATION

It will be evident, from the description of the various symptoms caused by plant viruses in their hosts, that the actual diagnosis of plant virus diseases is not altogether straightforward. The identification of a virus disease by the symptoms shown on any host plant is more of an art than a science, and while it is possible to become expert by practice, it is usually desirable to confirm one's diagnosis experimentally. Fortunately this is generally quite easy, it being sufficient to make a few inoculations of appropriate indicator plants whose reactions to particular viruses are well known. For example, the virus causing the break in wallflower may be identified by the symptoms that it causes in tobacco. A small part of the wallflower plant is ground up, the juice is rubbed gently over the leaves of a tobacco plant, and excess is washed off with water. In a few days, characteristic reddish lesions, having a chlorotic boundary, develop on the plant (figure 21).

The tobacco plant is a very useful test plant. Thus figure 25 shows the effect of potato X virus in a tobacco plant, which was inoculated from a potato plant which did not show any visible disease. The mild strains of potato X virus may not cause obvious 'local' lesions on the inoculated leaves of tobacco, and the leaf illustrated is in fact one of the younger leaves which has developed the systemic symptoms of the disease. This type of symptom takes about a fortnight to develop.

Another plant which is used very frequently as a test plant is *Nicotiana glutinosa*, and figure 22 shows the symptoms caused in this plant by strains of the tobacco mosaic virus. This virus is extremely common in tomato plants, largely owing to the habit of smoking; commercial tomato houses are usually heavily contaminated with the virus, strains of which have adapted themselves very well to the tomato. Many tomato growers, nevertheless, do not realise that their tomato plants are diseased. Figure 28 shows the symptoms due to a more obvious strain of this virus, known as tomato aucuba mosaic virus because the symptom that it causes is a brilliant yellow mottle, rather like that found on the leaves of the Japanese variegated laurel, *Aucuba japonica*.

Very frequently plants are found simultaneously infected with two or more viruses. For example, the virus shown in figure 16 came originally from a tomato fruit having three different viruses, and the *Campanula* in figure 4 had two viruses, as did the potato plant in figure 24. Separation of mixtures such as these is difficult, but may be accomplished by taking advantage of the different host ranges of the various viruses involved. Figure 26 shows one such separation. This virus came from a South American potato, and had the property, unusual for a potato virus, of causing a disease in cucumber. Transfer to the latter plant, therefore, automatically separated it from a number of other potato viruses. Other methods for separating complexes of viruses involve the stability of individual viruses to heating or ageing. Thus sap from the potato in figure 24, which has two viruses in it, will lose one (virus Y) on standing for a few days, leaving the stable virus X. Virus Y may be isolated by transmitting it from the original plant to another potato plant or to a tobacco plant, by means of an aphid, such as *Myzus persicae*, which does not transmit virus X.

Other methods of identification, which have limited use, include serological reactions using the serum from rabbits immunized towards the virus in question. In this method the rabbits do not develop any disease, but they produce antibodies which react specifically with sap from diseased plants. Unfortunately few plant viruses are present in sufficient concentration to react in this way.

Finally, a small number of viruses are sufficiently stable, and are present in such high concentration, that one can actually effect the identification by purifying the virus and examining its crystals under the microscope. Turnip yellow mosaic virus (figure 27) is one such virus; as it may be crystallized in a few hours, this method of identification is both certain and rapid.

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Linnaeus (1707–1778)

W. O. JAMES

This year marks the 250th anniversary of the birth of Linnaeus, an outstanding figure in the history of biology. This article includes a short biographical sketch—from which he emerges as a somewhat complex personality—but is rather more concerned with an assessment of the value and significance of the Linnaean system. While this had defects, notably its wholly artificial nature, it did at least bring order to the vast amount of descriptive information about plants which had been accumulated by the eighteenth century.

Linnaeus laid it down in his medical teaching that the first step towards health and happiness is to be born of young and vigorous parents in their full tide of sexual ardour: this advantage he considered himself to possess. His father, Nils, was perpetual curate of Stenbrohult in southern Sweden. On 6th March 1706, at the age of 32, he married the rector's daughter, and on 23rd May (NS) 1707 Carl Linnaeus was born. Close affection lasted for life between both parents and their firstborn.

Nils was unable, when the time came, to maintain his son for long at a university, but in a way he did even better. He endowed him with a nature that inspired such confidence and liking that a succession of wealthy and influential patrons made it possible for Carl to follow wherever his abilities and inclinations should lead. At Lund, at Uppsala, in Stockholm, and abroad in Holland, there was, at least intermittently, manna from heaven.

In his second year at Uppsala (1729–30) Linnaeus delivered a New Year's gift to his current benefactor in the form of a little tract *sponsaliorum plantarum*, which gave the first taste of his quality. Olof Rudbeck the younger, reluctantly responsible for the botanical teaching in the university and wanting to devote himself to other things, thereupon arranged for his gifted student to take over his lectures, and the attendances rose rapidly from eighty to four hundred. Even earlier than this, Linnaeus had been making a small income by private teaching.

Two years later he undertook a journey to Lappland, a prototype of the journeys made nowadays by members of undergraduate exploration clubs, but with one major difference. The offices of organiser, mineralogist, botanist, and zoologist were all filled by Carl Linnaeus: it was a one-man expedition. He applied to the Royal Society of Science in Uppsala for a grant of four hundred dalers towards an estimated requirement of six hundred; after some hesitation the grant was made, leaving, it is said, only one daler nineteen öre in the Society's coffers. The journey was attended with some danger and a good deal of hardship, which the young explorer saw no reason to minimize in his published diary. As he and his Lapp guide struggled across the Lycksele fells 'sometimes we came where no bottom was to be felt, and we were obliged to measure back our weary steps. Our half boots were filled with the coldest water . . . Had our sufferings been inflicted as a capital punishment, they would even in that case, have been cruel, what then had we to complain of? I wished I had never undertaken my journey.' But in the event he returned home fitter than he set out, and declared himself able to walk four times farther. Scientific results were enshrined in the *Flora Lapponica* and in a still very readable diary.[1]

After he had been seven years a student and no other prospect had appeared, Linnaeus decided he would have to earn a living as a practising physician. The Swedish fashion then was to qualify with a Dutch Doctorate of Medicine, and for this purpose he travelled to Harderwijk, which had a university much frequented by foreigners seeking medical degrees. He arrived on 18th June (NS) 1735 and received his degree, licensing him to practise, a week later.

In spite of this promptness, he already lacked funds to pay for his return to Sweden, and his second object in coming to Holland, the publication of the works he had prepared in Uppsala, was still unaccomplished. Again wealthy amateurs came to his help. He remained two and a half years, and during this time many of his most important books were published.

In the middle of his stay he made an excursion to England to see the collections of Sir Hans Sloane and the botanic gardens at Chelsea and

[1] Translated into lively English in 1811 by Sir James (Edward) Smith, first President of the Linnaean Society, under the title *Lachesis Lapponica*.

FIGURE 1 – *Wedgwood portrait medallion of Linnaeus based on the original by C. F. Inlander. Solander, who sailed with Captain Cook in the* Endeavour *and who was a pupil of Linnaeus, pronounced one of these medallions 'to be the best likeness of his old master that was ever executed'.*

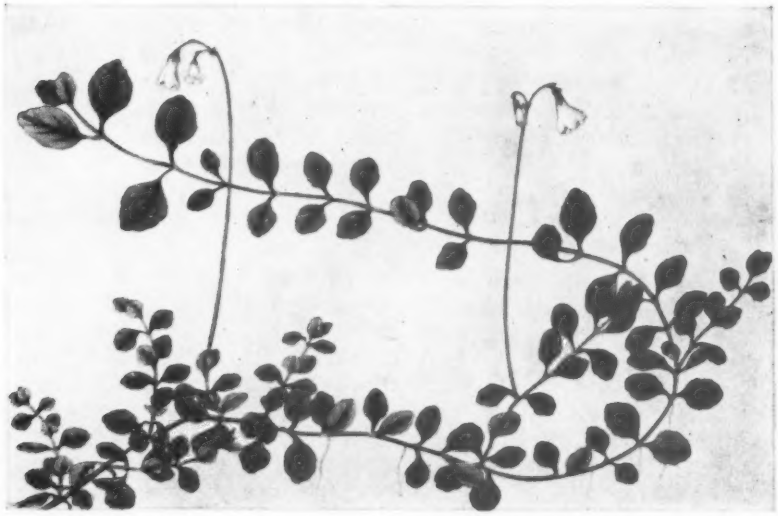


FIGURE 2 – Linnaea borealis *L. The genus was named after Linnaeus by his friend Gronovius in Holland, and is the basis of the decoration on a tea service preserved in the museum of the Botanic Garden at Uppsala.*

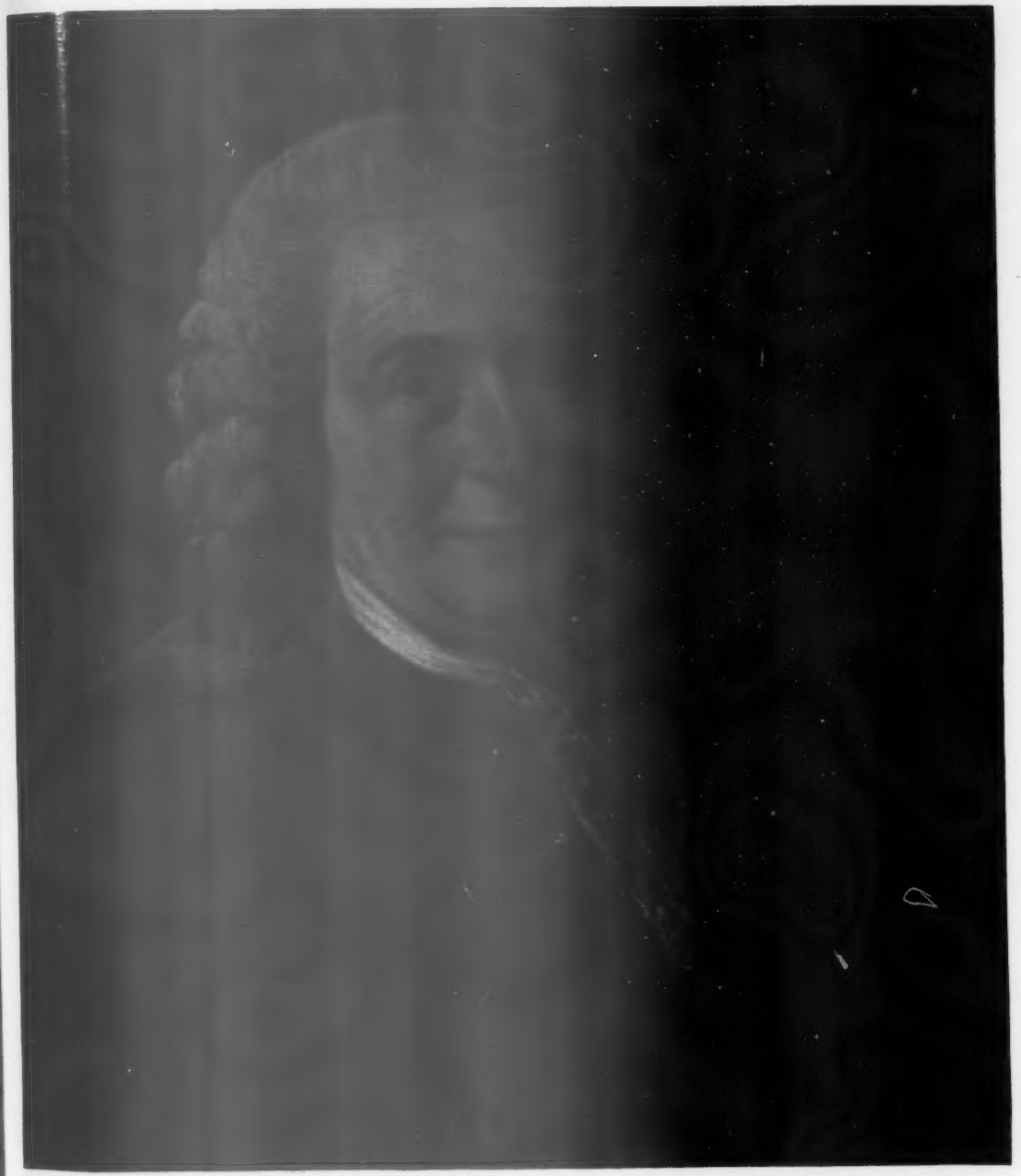


FIGURE 3 – *Linnaeus at the age of* 68. *Portrait in oils by A. Roslin, in the collection at Gripsholm. The signature is ten years earlier.*

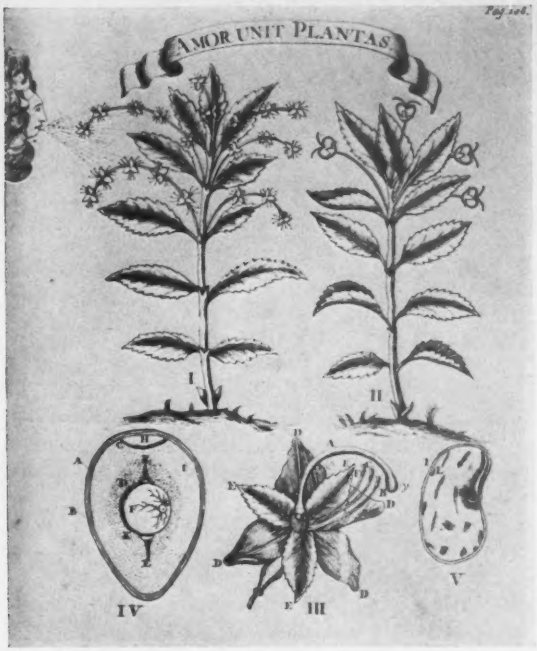


FIGURE 4 – *The diagram used to illustrate the Linnaean conception of the sexuality of plants published in the first volume of the* Amoenitates Academicae *in* 1749. *I and II illustrate pollination by wind; IV and V, his misleading comparison between a seed and an egg.*

Oxford. Philip Miller at Chelsea and J. J. Dillenius at Oxford received him coolly, but soon succumbed to his enthusiasm and charm. The English as a whole did not impress him favourably; he later wrote 'little do I love the race', and said that Dillenius, born in Darmstadt, was the only real botanist among them.

Linnaeus returned to Sweden in 1738 by way of Brussels and Paris, and set up as practising physician in Stockholm. After a slow start, he gained patients in court circles and a lasting connection with Count Tessin, head of the Hats party in the Riksdag. Through the latter's influence Linnaeus was put in the way of remunerative jobs, received the title of *Archiater* (royal physician), and was later (1753) made Knight of the Polar Star. He also became first president of the Academy of Science.

At the age of thirty-four Linnaeus was appointed a professor of medicine and botany at Uppsala and rejoiced at being 'freed from the wretched practice in Stockholm'. He was henceforward able to teach, collect, and investigate plants according to his fancy. He was an enthusiastic cultivator—another inheritance from his father—and developed the botanic garden until it was comparable with those he had seen abroad; during a period of emergency he even acted as his own head gardener. He was allowed to build an orangery and an official house, and bought himself a country estate at Hammarby where he lived in patriarchal style with his family, visited by students and foreigners. During the earlier years of his professorship he travelled about Sweden on government commission; but after 1749 he limited himself to a series

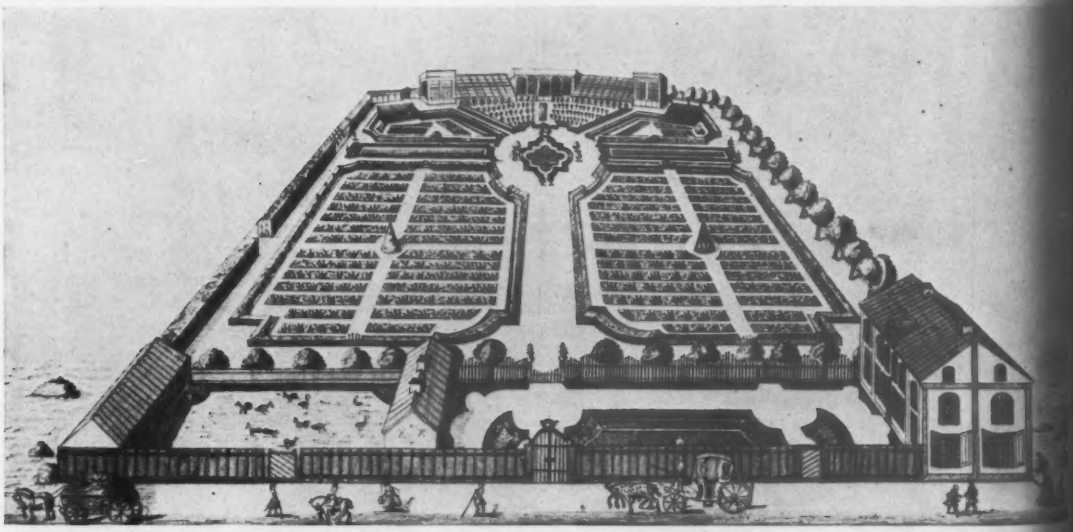
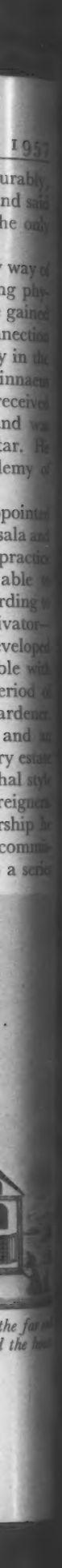


FIGURE 5 – *The Botanic Garden at Uppsala in* 1749, *from a contemporary engraving. The orangery encloses the far side and Linnaeus's official house stands in the right foreground. Much of the original layout has been restored, and the house is now a museum of personal relics of Linnaeus.*



of set excursions around Uppsala with his students. These were highly popular outings, often attended by two or three hundred people.

Flags flying, French horns blowing, kettle-drums throbbing,
And Carl Linnaeus marching at their head.

. . . . . .

And, afterwards, each with his own flower-fettered girl,
They'd dance the rest of the summer night away,

though the girls may be mostly authorized by Alfred Noyes' poetic licence.

Carl Linnaeus was a complex, highly self-conscious personality. At various times he wrote at least four autobiographical sketches, and a *philosophia humana* which is not inspiring. He also wrote a *Nemesis Divina*, ostensibly for the guidance of his son, who was said to care 'not so much for Flora as for the nymphs'; and it may be true that 'no man listened more than he to the tolling of death's bell'. He was still in the twenties when he asked, in a technical communication on botany, 'What do mortals more desire in this unsubstantial fleeting world than that . . . when our feeble frame decays and after death becomes noisome, some honourable remembrance of their names, however slight, should reach posterity, and endure yet a few days?'

Everything about himself he put on paper for others to read. He had the modesty of assured position, but also the complacency of achievement. He could write '*Linnaea* . . . lowly, insignificant, disregarded, flowering but for a brief space—from Linnaeus who resembles it'; but also 'I have been the greatest reformer in that science (botany) that ever existed'. Like Caesar, he commonly wrote of himself in the third person. He became a nabob of science and conferred the honour of a generic name upon a contemporary (Rudbeckia, Dillenia, and many others) with scarcely less sense of favour than the king ennobled his own to von Linné.

Some have elevated Linnaeus to the status of moral as well as natural philosopher, and have claimed for his idiosyncratic mixtures of Swedish and Latin a place in literature. English readers can best judge his discursive style in the very elegant translation of *Critica Botanica* made by Sir Arthur Hort.

But it was his service to biological taxonomy that was his contribution to human knowledge, and for this he had three outstanding assets: a tidy mind, the gift of clear verbal description, and a complete and utter belief in the value of what he

FIGURE 6 – *Sketch from Linnaeus's Lappland diary. 'In every river a wheel is placed contrived to lift up a hammer for the purpose of bruising flax'. Linnaeus's pencil did little to help his pen.*

was doing. He was, in his own words, a born methodizer; and he was the first to achieve critical diagnoses of plant and animal species in place of somewhat rambling or unmethodical descriptions. But the third asset was perhaps the most potent: never did he doubt the wisdom of spending life, health, and means in perfecting a Linnaean system of nature. All through life he worked with a fury that may have prematurely broken down his strength; he believed himself that it did, and his last decade was overshadowed by progressive ill-health.

His contemporaries accepted his own estimate that he had wrought a revolution, but there were really many indications of the coming change. To some extent he has benefited by the tendency of big reputations to absorb small ones, a process he even seems to have done something to assist.

The binomial system of employing a latinesque generic noun followed by a specific adjective was used systematically for the first time by Linnaeus, though he did not, in fact, use it consistently until 1753, when most of his work was already done, and Caspar Bauhin (1560–1624) had listed many binomials in his *Pinax* a century earlier. Linnaeus's greatest contribution to nomenclature was more fundamental.

In an age of poor communications and no co-ordination, a fearful synonymy had inevitably entangled natural history, and the more industriously the collectors, the botanists, and the zoologists worked, the worse this grew. Many names could all too easily be attached to a single species, and there was not even agreement about how a name should be arrived at, nor what names were suitable and what were not. Linnaeus laid down the required system in a long series of maxims varying from the weighty to the trivial, and he got others to accept it, even though it often meant sweeping aside much of their own work. His

aphorisms are still the firm foundation of the modern international rules of biological nomenclature, and they, rather than the binomials, are his true memorial.

The idea of classification cannot be considered any one man's discovery. The seventeenth-century naturalists instinctively grouped together species that resembled one another. The more numerous the points of resemblance the more natural, in the sense of formal logic, was the grouping. But, though many such groups were apparent, the whole range of living things obstinately refused to divide itself in any orderly way among them. Early attempts at arrangement aimed at a natural system, but came more and more to rely on arbitrarily chosen single characters. As a result, they were partly natural, but to a much larger extent artificial.

The arrangement of plants proposed by Joseph Pitton de Tournefort (1656–1708), at first used by Linnaeus, rested mainly on the characters of the floral envelope and involved many difficulties. The Linnaean system, based solely on the sexual organs, was more—indeed, completely—artificial. As a means to classification the styles and stamens had no deeper significance than the petals, but they had far greater convenience; the only qualification needed for placing plants in the Linnaean system was the ability to count up to twenty. It became a favourite occupation of Young Ladies.

Linnaeus was probably the first to realize clearly that a natural classification could not be achieved by artificial means and to make a deliberate choice: he chose an empirical system because a rational one was out of his reach. He explicitly stated the need for continuing the struggle and made suggestions for this where they seemed possible. An entirely natural classification of flowering plants, for example, is still a desideratum. In defence of Linnaeus it may also be said that the temporary acceptance of formalism gave taxonomy a badly needed breathing-space and, further, that the idea of natural classification did not then carry the overriding importance that evolution gave it a hundred years later. He considered the problem of origins, but he made nothing of it.

Linnaeus tidied up the mess of an era and so cleared the way for its successor; but he made little contribution to the new age. Though Hooke, Malpighi, and Grew had shown the way, he rarely used a microscope and then not always with fortunate results. As to the real nature of organisms, their intimate structures, and their physiology, he seems to have had little curiosity.

In the year of Linnaeus's death Gilbert White enlarged on the theme that the botanist 'should be by no means content with a list of names: he should study plants philosophically, should investigate the laws of vegetation'. For many years, however, most botanists were satisfied to sun themselves in the *pax Linnaea*. By his very success he put botany into a strait jacket from which it with difficulty freed itself in a century. But to blame Linnaeus for this, would be to visit the iniquity of the children upon the father.

Book reviews

ALCHEMY

Alchemy, *by E. J. Holmyard. Pp.* 281. *Penguin Books Limited, Harmondsworth.* 1957. 3*s.* 6*d. net.*

It would be difficult to find a better qualified expositor of alchemy than Dr Holmyard. With equal appropriateness, this book, being one of a numerous brood of Pelicans, bears the symbol of that devoted bird, the alchemical pelican, on its cover. In its fullest aspect alchemy is a subject so complex and tangled, and extending over so long a period in human history, that a complete treatment in a volume of this size would be out of the question. The author has therefore wisely concentrated on exoteric alchemy. In contrast to esoteric or mystical alchemy, this was concerned mainly with practical ideas and experiments aimed at producing the hypothetical philosopher's stone and the consequent achievement of transmutation or multiplication, otherwise the artificial making of gold and the related elixir of life. He has covered this field, within the ambit of a dozen chapters, with his accustomed fluency and thoroughness. He writes, of course, with particular force and authority in his earlier chapters on Greek and Islamic alchemy: this part of the book in particular will be appreciated and valued by the expert and scholar even more than by the lay reader. For the specialist a closer documentation would have added to the worth of an illuminating treatise. Besides some text figures, the book contains an excellent selection of thirty-six nicely produced illustrative plates. The publishers, themselves notable exponents of the art of multiplication, have combined with the author in producing a very attractive and useful volume.

J. READ

THEORY OF STATISTICS

Statistical Methods and Scientific Inference, *by Sir Ronald Fisher. Pp. viii* + 175. *Oliver and Boyd, Edinburgh.* 1956. 16*s. net.*

Sir Ronald Fisher has long been the leading figure in the development of a theory of scientific inference from statistical information; even the most active

in exploring alternative lines of reasoning have owed much to his pioneering thought. Yet any student of Fisher's theory is obliged to read papers published over a period of 35 years, with the consequent difficulty of making allowance for changes in emphasis as Fisher's own mastery has grown.

Statisticians will welcome this distillate of the earlier papers: principles are unaltered, but an illuminating and characteristically Fisherian presentation relates them to modern statistical practice. Fisher emphasizes the difference between inference appropriate to scientific research and that needed in acceptance and decision techniques, and shows with remarkable clarity the nature of likelihood and the fiducial argument. One example illustrates especially well the role of ancillary statistics. The last two chapters require mathematical sophistication in the reader, but every experimental scientist could profitably study the first four. For some, the necessity of referring to the early papers will remain, but that task will be greatly eased by a discussion dated 1956. Only some unhappily phrased personal comments mar a great book that will consolidate present ideas and stimulate many advances in statistical theory and practice.

D. J. FINNEY

MATHEMATICS OF DIFFUSION

The Mathematics of Diffusion, *by J. Crank. Pp. vi + 347. Clarendon Press, Oxford; Cumberlege, London.* 1956. 50*s. net.*

This book is not concerned with the molecular theory of diffusion, and, as Dr Crank remarks in his preface, a more precise title would be 'Mathematical solutions of the diffusion equation'. The subject has a long history and perhaps some may think it is played out; in reality, there have been important developments in recent years and the present account is opportune.

The first six chapters deal with solutions of Fick's equations with constant diffusion coefficient for various boundary conditions; the Laplace transform is extensively used as well as the older methods. More complicated problems, such as diffusion with a moving boundary, simultaneous diffusion and chemical reaction, and systems with variable diffusion coefficients, are discussed in considerable detail in later chapters. The final chapter deals with the simultaneous diffusion of heat and moisture; problems of thermal diffusion or simultaneous diffusion of two solutes with interacting fluxes are not, however, considered.

All those interested in diffusion problems should find the book of value; the treatment of problems involving variable diffusion coefficients, in particular, provides a most useful account of recent work on this topic, and the earlier chapters give an unusually clear and well-balanced summary of the more 'classical' part of the subject.

J. N. AGAR

QUANTUM PHYSICS

Quantum Field Theory, *by H. Umezawa. Pp. xiv + 364. North-Holland Publishing Company, Amsterdam.* 1956. 70*s. net.*

This is a highly formal approach to a highly formal subject, and although we are told—and it is true—that the book starts from first beginnings, it is not for the beginner. A fair knowledge of group theory and the special theory of relativity is presupposed; but this is no adverse criticism, since the overloading of books with extraneous matter is a tendency to be strongly resisted in this age of high prices.

By most resolute pruning, the author has succeeded in providing a really comprehensive treatise in a comparatively small compass, and in particular the account of the relativistic wave equation, which occupies the first hundred pages, is masterly. After that, more attention to physics in describing field theory proper would have enlivened the somewhat dry mathematical pages. A more serious fault is that results sometimes appear stated rather than proved; for example, equation (8.6).

This reviewer strongly approves of positons and negatons. But why 'proper field', when 'self field' (used once) is a much more expressive as well as a firmly established term? However, these are small matters in an excellent work, which should remain a standard treatise for many years. L.R.B.ELTON

NUCLEAR SCIENCE

Annual Review of Nuclear Science, *Vol. V, edited by James G. Beckerley. Pp. ix + 448. Annual Reviews Inc., Stanford, California.* 1955. $7 *net.*

Here again is the by now well tried mixture of pure and applied physics, radiochemistry, and biology. This series now follows an accepted pattern, and general remarks made about previous volumes apply equally to the present one.

Much knowledge has accumulated of late about nuclear structure, and three articles deal in different ways with this subject. Accounts of the instruments of nuclear physics include the bubble chamber for the first time, as well as the nuclear reactor as a research tool. Surprisingly, there is no mention of fundamental particles—this has not happened before in this series. The speed of advance of nuclear physics is indicated by the fact that after this pause the past year has produced the anti-proton, the neutrino, and the anti-neutron.

The articles are becoming increasingly specialized, and the physicist is soon out of his depth among the chemists and biologists. The article on 'Removal of radio-elements from the mammalian body', however, deserves to be widely read, for behind the account of experiments on rats hide the horrors of war. L. R. B. ELTON

NUCLEAR PHYSICS

Progress in Nuclear Energy, *Series I:* Physics and Mathematics, *Vol.* 1, *edited by R. A. Charpie, J. Horowitz, D. J. Hughes, and D. J. Littler. Pp. x + 398. Pergamon Press Limited, London.* 1956. 84*s. net.*

The original impetus to this new series of reviews on nuclear science, of which this is the first volume to appear, was provided by the Geneva Conference. The proceedings of this conference have already appeared in print; in this series they are reviewed and critically evaluated. This in itself is a laudable task, but whether it justifies the whole apparatus of a new and truly gigantic review project is debatable. The present volume is not suitable for the non-specialist, and in some of the fields discussed even the pure nuclear scientist would find himself in this class.

The title is misleading. Mathematics occurs *passim*, as it must in any paper on physics, but there is little attempt to present any mathematics as a logical whole. More irritating, some of the mathematics is described in words rather than in symbols. This does not make it easier reading for either mathematicians or non-mathematicians. L. R. B. ELTON

PHYSICS OF REACTORS

Peaceful Uses of Atomic Energy. Proceedings of the International Conference in Geneva. *Vol. II,* Physics, Research Reactors. *Pp.* 471. *Vol. III,*

Power Reactors. *Pp.* 389. *Vol. IV*, Cross-Sections Important to Reactor Design. *Pp. viii* + 357. *Vol. V*, Physics of Reactor Design. *Pp. viii* + 545. *United Nations, New York; Her Majesty's Stationery Office, London.* 1956. 57*s.*, 54*s.*, 54*s.*, and 63*s. net respectively.*

The International Conference on the Peaceful Uses of Atomic Energy, held in Geneva during August 1955, was the occasion for the release of a great fund of technical information on all aspects of the subject. These four volumes contain the proceedings of the sessions which discussed, in considerable detail, present knowledge on the physics and design of all types of nuclear reactors. The papers presented, together with the admirably reported discussions, allow a comparison to be made of the present achievements and future programmes of the various countries engaged in this field.

Considering the volumes in order, the first half of volume II contains papers on a number of important topics in basic nuclear physics, in particular, fission physics and inelastic neutron scattering. The second half covers the construction of, and operating experience with, a number of research reactors. The reactors described include swimming-pool reactors, water boilers, and the United States reactor for testing materials, light and heavy-water-moderated reactors of the U.S.S.R., the Saclay reactor of France, J.E.E.P. of Norway, and B.E.P.O. of the United Kingdom. The importance of this type of reactor for providing information on the design of reactors for high powers is well demonstrated.

Volume III is clearly one of the most important volumes of the Proceedings, because it contains an account of the design of all the large-power reactors at present under detailed consideration. One of the most striking features is the wide diversity of possible designs, all aimed at the development of economic power plants. Not unnaturally, only a few of the reactors described are in operation. Accounts of operating experience are limited to the water-cooled graphite-moderated enriched uranium reactor of the Soviet Union, the American boiling-water reactor, and the EBR I sodium-potassium-cooled fast reactor. It is apparent that these three reactors are experimental projects rather than full-scale power plants.

The combined papers in volume IV give an excellent survey of the experimental methods for measuring nuclear characteristics of fissile materials. Much attention is given to the various time-of-flight techniques, using either a mechanical chopper or a pulsed-neutron source, for making measurements with neutrons of a known energy. The wealth of numerical data quoted makes this volume one of the most comprehensive reference books on this subject so far published. In many cases, where similar measurements have been made by American, British, and Russian laboratories, there is remarkable agreement between the values quoted.

Volume V contains the papers which deal with the nuclear physics problems associated with reactor design. The reactor problems discussed cover thermal, intermediate, and fast neutron systems. Many of the papers deal with experimental observations on reactors and their theoretical interpretation. The lack of continuity between the different papers is perhaps more apparent in this volume than in the others. However, this is offset by the large quantity of experimental data on reactor physics which has been collected into one volume.

J. E. R. HOLMES

HYDROGEN PEROXIDE

Hydrogen Peroxide, *by W. C. Schumb, C. N. Satterfield and R. L. Wentworth. Pp. xiii* + 759. *Reinhold Publishing Corporation, New York; Chapman and Hall Limited, London.* 1955. 132*s. net.*

The widening applications of hydrogen peroxide have greatly stimulated the study of its manufacture and properties. It is therefore timely that the first comprehensive volume on this subject in English should now appear. The authors are particularly well qualified for the task since they themselves have made valuable contributions to knowledge of the subject.

An interesting historical introduction is followed by two extensive chapters on methods of formation and manufacture. This information is given in adequate detail, but the reader will find the authors have drawn much on published information about German practice. An outline of the autoxidation process, now operated industrially, is given, but the book was published before information was released on another organic method of production based on the oxidation of *iso*propyl alcohol.

The physical and chemical properties are particularly well treated. The data on physical and thermodynamic properties are well chosen, and the effect on radiation is dealt with in some detail. One chapter is almost entirely devoted to structure, while another discusses the mechanism of reaction and outlines the reactions with inorganic and organic compounds. Decomposition in the vapour and liquid phase is extensively dealt with, and there is an authoritative discussion of stability problems. The scope of the analytical section is rather limited, while the uses of the material are treated in descriptive outline, including reference to applications in the propulsion field. The final chapter gives a useful but summarized account of inorganic peroxy compounds.

The whole work is pleasingly presented, and the authors have compiled a book which should become a standard reference for some time to come.

W. S. WOOD

ORGANIC CHEMISTRY

Lehrbuch der organischen Chemie (*third/fourth edition*), *by Hans Beyer. Pp. xvii* + 690. *S. Hirzel Verlag, Leipzig.* 1955. *DM.* 22.50 *net.*

This is a completely revised edition of a general textbook of organic chemistry in which much attention is paid to the electronic theories of reaction mechanisms. Classification of reactions is introduced early (under alkyl halides); the reactions of olefins bring in the discussion of π-bonds; polymerization is shown as a rational process; recent contributions of German research and technology are described. Petroleum, plastics, stereochemistry, chemotherapy, coenzymes, the citric acid cycle, and alkaloids are all competently dealt with. Because the information on most topics has been skilfully selected, it is difficult at first to see how so much ground has been covered. There are omissions in some sections which many readers will regret; for example, carotenoids are dealt with in four pages by omitting discussion of degradation, syntheses, or even colour. There is a confusing lack of uniformity in the method of printing the formulae of ring compounds: to note only one example, the carbon atoms are omitted from naphthaquinone (p. 431), while anthraquinone (p. 436) has exaggerated C=O groups attached. But the general effect of the book is to give the reader a fascinating picture of the scope of organic chemistry, especially of its recent triumphs. The author's style is clear and

the printing is good. For honours students this book should provide stimulating views of the subject. J. G. SMITH

ORGANIC CHEMISTRY

Perspectives in Organic Chemistry, *edited by Sir Alexander Todd. Pp.* x + 527. *Interscience Publishers, New York and London.* 1956. 55*s. net.*

This tribute to Sir Robert Robinson on the occasion of his 70th birthday, consisting of eighteen essays by leading authorities in Europe and America, among whom are some of Sir Robert's many distinguished former students, is far more than a conventional *Festschrift*. Possibly the contours of organic chemistry have become so enlarged during the twentieth century that never again will it be possible for any one man to acquire so penetrating an insight into, and wield so wide and decisive an influence on, the subject as a whole as Sir Robert has done.

It is not possible to give an account of all the topics included in the present 'Perspectives'; suffice it to say that they cover practically all modern organic chemistry and that they should primarily serve, as stated by E. L. Hirst, not so much for 'taking stock of achievement in a field which has become static, as for indicating some of the many growing points and the general nature of the problems which are to be faced'.

Alkaloids, biosynthetic theories, steroids, the concepts of aromaticity, resonance, and reaction mechanisms are all represented with a delightful lucidity which will ensure that this work will live as a reference book for many years to come. No organic chemist can fail to find this volume rewarding from cover to cover, and its usefulness is increased by the many references and structural formulae. It is perhaps invidious to select individual chapters for comment, but Woodward's 'Synthesis' is surely outstanding for its elegance and its emphasis on planned approaches having special reference to modern selective methods and reagents. Todd on nucleic acids, Butenandt on genetics, Ziegler on metallo-organic syntheses, and Pauling on resonance represent other fascinating articles in this valuable collection. I. M. HEILBRON

ORGANIC CHEMISTRY

A Textbook of Practical Organic Chemistry, including Qualitative Organic Analysis (*third edition*), *by Arthur I. Vogel. Pp.* xxvii + 1188. *Longmans, Green and Company Limited, London.* 1956. 60*s. net.*

In this edition the whole text has been exhaustively revised, and a twelfth chapter on semi-micro technique added. A 16-page appendix is devoted to infra-red and ultra-violet spectroscopy. Now that each page prominently bears its chapter and section number, reference from one section to another is greatly facilitated. The book does succeed in giving a full, clear account of the techniques of organic chemistry in one volume, but omission of all references to the sources of the great mass of information provided reduces its usefulness.

Qualitative analysis is authoritatively dealt with, but there is one change from the wording of the second edition which may lead to errors. On page 1041, in testing for nitrogen in presence of sulphur, it is recommended that the precipitate of ferrous sulphide be filtered off before acidification of the filtrate. Experience shows that in this procedure the ferrocyanide is usually removed with the sulphide.

The book, which is remarkably free from errors, is well written and produced. It should be available in every chemical laboratory. J. G. SMITH

POLYESTERS

Polyesters and their Applications, *by J. Bjorksten, H. Tovey, B. Harker, and J. Henning. Pp. viii* + 618. *Reinhold Publishing Corporation, New York; Chapman and Hall Limited, London.* 1956. 80*s. net.*

In a book of over 600 pages it must be almost unique to find the bibliography beginning on page 253. The authors and their collaborators have classified over 1000 relevant patent references and more than twice that number of references to technical articles and books. The amassing of this wealth of information is the *raison d'être* of the whole book and to the potential user an invaluable time-saver. A simple introduction to the general concept of polymer chemistry is followed by a general review of manufacturing and processing techniques. Pride of place goes to the unsaturated polyesters, whose tonnage far exceeds that of the saturated compounds, which find their main outlet as melt-spun fibres.

The market for unsaturated polyesters, mainly as reinforced thermosetting resins, is very diverse and favours small-scale operations. This is brought out by the chapters on fillers, shaping, and finishing, and a survey of available commercial resins, followed by an interesting chapter on 'Tailor Making Polyesters'.

The balance between low cost of raw materials and tooling and comparatively high processing cost determines the applications to which polyesters are put: some discussion of the economics of the subject would, therefore, not have been out of place. G. I. RUTHERFORD

GEOMAGNETISM

Lectures on Rock Magnetism, *by P. M. S. Blackett. Pp.* 131. *The Weizmann Science Press of Israel, Jerusalem.* 1956. $5 *net.*

The remarkable fact that many rocks are apparently able to retain a record of the magnetic field prevailing at the time of their formation has aroused considerable interest. Professor Blackett has made valuable contributions to the subject by his improved design of the astatic magnetometer and through his leadership of an active group of workers in the field. The present volume is a stimulating discussion of the results so far obtained. Because the study of rock magnetism makes contact at various points with a number of widely differing geological and physical subjects, such as palaeoclimatology, the physics of the earth's crust, and the theory of ferromagnetism, it is not to be expected that Professor Blackett's exposition will satisfy the various specialists in these fields.

Little is said, for example, about the evidence for polar wandering, although this is stronger than the magnetic evidence at present available for continental drift. Further, the statistical treatment of results, which is absolutely essential if measurements of rocks from different places are to be compared, is dismissed with a comment that 'they would give an undue impression of accuracy'. To exhibit the results obtained by his group on the Triassic sandstone of England, the author uses histograms and radial polygons of declination and inclination where the use of the well-known stereographic projection is much to be preferred.

The discussion of the results on the Pilansberg dykes of South Africa appears to the reviewer to be misleading. The results of Gough are compared with those of the author's group on the Triassic rocks of Great Britain and France, and are held to show that Africa and Europe have drifted as a

unit. However, the age of the Pilansberg dykes is definitely earlier than Permian and may be Pre-Cambrian, while the author gives their age variously as 300 or 400 million years, nearly twice that of the British and French rocks with which he is comparing them. S. K. RUNCORN

BIOCHEMISTRY

Currents in Biochemical Research, 1956, *edited by David E. Green. Pp. xvi* + 697. *Interscience Publishers Inc., New York; Interscience Publishers Limited, London.* 1956. $10 *net.*

This volume is the third of a series of essays with which the present editor has been associated. The series began in 1936 with a volume edited jointly by Dr Green and Dr Joseph Needham; a second volume was edited by Dr Green in 1946. The outstanding success of these volumes prompted Dr Green and the publishers to collect a new series after an interval of ten years. Their aim has been 'to communicate to non-specialists an overall impression of the present status of the significant problems in each field, to point up the broad strategy of current research, and finally, to speculate on the likely paths of future research'. Dr Green has succeeded in securing the collaboration of twenty-seven leading biochemists, including M. Calvin, B. Chance, C. F. Cori, L. F. Leloir, F. Lipmann, D. Nachmansohn, E. Racker, F. Sanger, D. Shemin, S. Spiegelman, H. Theorell, while the editor himself contributes a preface outlining the major achievements and trends of contemporary biochemistry. The level of the essays certainly matches those of the previous volumes. The articles make most stimulating and informative reading, alike to the specialist working in the field and to the scientist working in remoter subjects, including the non-biochemist. The contributors have taken an unusual opportunity of discussing their chief interests from a general point of view and of expressing speculative thought. H. A. KREBS

CHROMOSOME BOTANY

Chromosome Botany, *by C. D. Darlington. Pp. xii* + 186. *George Allen and Unwin Limited, London.* 1956. 16*s. net.*

Professor Darlington is intensely aware that many aspects of botany as taught in both universities and schools have degenerated into arid formalism. That this is so is only too evident from the questions set in examinations, a number of which could well have been set a hundred years ago. The situation in botany, in fact, is similar to that conceived by Newman when referring to another discipline. 'We have a vast inheritance, but no inventory of our treasures. All is given to us in profusion; it remains for us to catalogue, sort, distribute, select, harmonize, and complete. We have more than we know how to use; stores of learning, but little that is precise and serviceable'.

This book is of great importance because it does attempt to co-ordinate the known facts of chromosome behaviour, and because it brings to university students a whole new integrated approach to fundamental aspects of both pure and applied botany. This urgently needed synthesis may ultimately permeate both school and university teaching.

It is by no means a perfect book. The author is often engaged in goading, and pursuing with guided missiles charged with heavy sarcasm, helpless and already defeated conventional taxonomists, who are after all worthy individuals.

Many geneticists would not accept the author's ideas about the 'polygene' as set out on page 4. The statement is here made that 'polygenes . . . are sometimes recognizable; in the resting nucleus they wear a thick coat of sticky, nucleic acid and at metaphase they may suffer from the reverse conditions of nakedness or nucleic acid starvation. They are known as heterochromatin.' The book is somewhat marred by such personal opinions and surmises, but perhaps unavoidably, since they are the vivid expression of genius and should so be interpreted by students.

S. C. HARLAND

BRITISH FLORA

The History of the British Flora, *by H. Godwin. Pp. viii* + 384. *Cambridge University Press, London.* 1956. 90*s. net.*

The purpose of this book is to describe the methods available for the historical study of the British flora and the results so far achieved, both with special reference to the Quaternary era. After a brief summary of the materials available—seeds, fruits, leaves, wood (sometimes as charcoal), and pollen grains—the author proceeds to a discussion of Quaternary chronology. The use and correlation of biological, archaeological, and physical (radiocarbon) methods of dating are given detailed and critical consideration, and the importance of bog stratigraphy as an index to prevailing conditions comes in for special mention.

These background chapters are followed by a detailed plant list giving the historical records of more than 700 species, including cereals and other crop plants. The amount of information it is possible to provide (as judged by the length of the individual entries) appears to be correlated with the abundance of pollen produced by the species—a sufficient indication of the pre-eminence of palynology in this field. Finally, a description is given of the changing pattern of the vegetational cover of the islands during the vicissitudes of the Quaternary age, with its successive glaciations and interglacial periods leading down to medieval times.

Throughout the book the emphasis is on the direct evidence obtainable from suitable sites. The aim is stock-taking, and the attitude one of caution against premature definitive pronouncements.

The text is printed in double columns on a large page and is abundantly and handsomely illustrated in line and half-tone. W. O. JAMES

PARASITES

Parasites and Parasitism, *by Thomas W. M. Cameron. Pp. xix* + 322. *John Wiley and Sons Inc., New York; Methuen and Company Limited, London.* 1956. 35*s. net.*

This book, as the author explains, is not a textbook of medical or veterinary parasitology. Too often, he thinks, the real nature of parasitism is clouded by the concept of disease, and in this work he tries to get away from this. Writing for readers who have a 'working knowledge' of biology but no special knowledge of parasitology, he devotes the first section to the bacteria, fungi, spirochaetes, rickettsias, viruses, and Protozoa; the second to the coelenterates, tapeworms, flukes, and roundworms; the third to the ringed worms (Annelida), the arthropods, the molluscs, and the few vertebrates that have adopted parasitism. The rest of the book deals with the host and its reactions, parasitism, infectious disease, the distribution of parasites, their control, and their host-specificity and evolution. The book ends with a bibliography, a glossary, an outline of the zoological classification of parasites, and an index.

The well-written text will stimulate thought. Some readers may disagree with some of the author's views, but these are based on his extensive original

work on parasites and on many years of teaching. The book is attractively produced, and the original and instructive line illustrations add much to its value.

G. LAPAGE

ANATOMY OF BEES

Anatomy of the Honey Bee, *by R. E. Snodgrass. Pp. xiv + 334. Cornell University Press, New York; Constable and Company Limited, London.* 1956. $6 *net.*

The first work on the anatomy of the honey-bee by the author was published in 1910 as one of the early Technical Bulletins of the United States Department of Agriculture, and many of the admirable line drawings prepared at that time reappear in this book. In 1925 the work was expanded to form the 'Anatomy and Physiology of the Honey Bee'; for many years this both provided an excellent survey on the honey-bee itself and served as a most useful primer on the physiology of insects in general. In its present form the book has been virtually rewritten. It now deals almost exclusively with matters of structure, and does so in the clear masterly style that we have come to expect from the doyen of insect anatomists. As always, Snodgrass is constantly interested in the functioning of the structures described; but of 'physiology' little remains, and naturally enough that does not always reflect current ideas. But on its real topic, the anatomy of the bee, the book appears to be admirably up to date, even including some references of 1956.

V. B. WIGGLESWORTH

MAMMOLOGY

Traité de zoologie. *Vol.* XVII. Mammifères. Les ordres: anatomie, éthologie, systématique, *edited by P.-P. Grassé. Pt. I, pp.* 1170; *Pt. II, pp.* 1171–2300. *Masson et Cie, Paris.* 1955. *Pt. I: paper covers, Fcs* 11 000 *net; bound, Fcs* 11 800 *net. Pt. II: paper covers, Fcs* 11 000 *net; bound, Fcs* 11 800 *net.*

The difficulty of writing a satisfactory zoological treatise is particularly apparent when dealing with Mammals and Man, where the data come from such varied sources. That Professor Grassé and his colleagues have mastered the problem successfully is shown above all by the fact that their great work is readable. The writing is fresh and terse; the typography and illustrations are excellent. One reads on through order after order, happy to recognize old facts in fresh settings and to learn many new ones. The book triumphantly demonstrates that the facts of animal life can be well presented around a framework of anatomy. The arrangement of the book follows a well worn morphological plan laid down by Cuvier, Owen, Gegenbaur, and Goodrich, to mention only a few. With an outline of the organization of each animal type as a basis it is then possible to proceed to relate a mass of facts about the physiology, reproduction, bionomics, and behaviour of the animals.

J. Z. YOUNG

OTOLOGY

British Medical Bulletin, *Vol. XII, No. II* (Neuro-Otology). *Pp.* 91–160. *The British Council, London.* 1956. 15*s. net.*

In the words of Sir Bryan Matthews in his introduction, 'the present number of the *Bulletin* gives clear evidence of the active state of otological research and its present fruitfulness'. Authoritative articles by workers in Britain on such varied topics as the technique of cutting histological sections of the internal ear, the formation and chemistry of endolymph and perilymph, the physiology of hearing and of the vestibular apparatus, the diagnosis and treatment of different types of deafness, the pathology and symptomatology of disorders of the labyrinth and of the central connections of the eighth nerve, and the hereditary lesions of the labyrinth in 'dancing mice' appear under the general editorship of C. S. Hallpike, who himself is author or part-author of four of the contributions.

The emphasis in most cases is naturally on the clinical applications of recent additions to knowledge, but physiologists, pathologists, anatomists, and zoologists will welcome this valuable survey no less than otologists and neurologists. Particularly striking are the advances which have been made by the use of modern techniques in electrophysiology, of pure-tone electronic audiometers, of refined caloric tests, and of very delicate microchemical analysis.

R. S. CREED

CEREBRAL CORTEX

The Organization of the Cerebral Cortex, *by D. A. Sholl. Pp. xvi + 125. Methuen and Company Limited, London: John Wiley and Sons Inc., New York.* 1956. 18*s. net.*

It is pleasing to find such a clear and concise account of the cerebral cortex. Inevitably, much has been omitted or treated in a summary fashion, yet the book is not superficial. Dr Sholl has restricted the account throughout to those features of the cerebral cortex which appear to him to be significant for the understanding of its mode of operation. It is valuable to have his well informed criticism of the old topographical work. In fact the whole book is remarkable for the very high level of critical comment. The constructive side is less notable. The new quantitative histology seems still to be too rudimentary for the development of precise hypotheses relating to cortical activity. Yet there is great promise in this attack, and Chapter 4 is a particularly valuable exposition of Dr Sholl's fine work on the 'Quantification of Neuronal Connectivity'. The chapters on physiological, clinical, and psychological investigations provide good summaries, but will appear inadequate to specialists. For example, most neurophysiologists would regard synapses as structures highly specialized for the operation of chemical transmitters, and not characterized merely by a close apposition of two nervous structures. Again, there is now no justification for assuming that electrical fields are effective in neuronal interaction, and the 'domain' hypothesis of Cragg and Temperley thus has no sound experimental foundation. The related theory of Beurle avoids this criticism and provides an excellent illustration of Sholl's thesis that the functioning of the cortex should be treated in terms of a model that is based on the concept of probability and is discussed in statistical language.

J. C. ECCLES

MEDICAL RESEARCH

Ergebnisse der medizinischen Grundlagenforschung, *Vol. I, edited by K. Fr. Bauer. Pp. vi + 855. Georg Thieme Verlag, Stuttgart.* 1956. *DM.* 129 *net.*

This is one of a new series of short monographs dealing with topics which form the scientific background of medicine. The editor states as the reason for this new venture that other reviews address themselves in the first instance to specialists and are often unsuitable for the clinician; it is the aim of the present series to present articles comprehensible to medical scientists who have no intimate knowledge of the basic sciences. The volume contains nineteen papers. They are selected from a wide range of subjects, including biochemistry, biophysics, allergy, embryology, histology, nutrition, endocrinology, and bacteriology. Morphology is represented by a review by

Ashton and Zuckerman entitled 'Measurement and Number in Morphology'. The majority of the authors are drawn from Germany and the papers are all published in German, but Sweden, Switzerland, Japan, France, Great Britain, and the United States are also represented. Many of the articles fulfil the editor's intentions and are likely to be of real value to medical scientists.

H. A. KREBS

ATMOSPHERIC POLLUTION

Atmospheric Pollution—Its Origins and Prevention (*second edition*), *by A. R. Meetham. Pp. viii* + 302. *Pergamon Press Limited, London.* 1956. 63*s. net.*

Since the first edition of this book appeared, increased attention has been focused on the evil effects of air contamination. The second edition is an attempt to bring the work up to date in the light of the considerable new information elicited at many conferences in Britain and America and by the reports of the Air Pollution Committee appointed by the British Government.

The additional matter is dealt with in a new chapter of 32 pages. For its size, the scope of the book is ambitious. It covers the whole range of relevant subjects—the origin and availability of fuels; the properties of wood, peat, and all members of the coal series in their raw and prepared states; hazards of mining; petroleum and natural gas; carbonization and hydrogenation; generation of steam and electricity; industrial furnaces and domestic fireplaces—before proceeding to the main theme of atmospheric pollution in all its details. The author has succeeded in presenting this all-embracing compilation in a readable form by clearly outlining principles rather than by dilating on descriptive details.

The author frankly admits having called on his judgment and conjecture more frequently in the new chapter than in other parts of the book. He certainly gives full rein to his ingenuity when he explains the physics of the formation of the catastrophic London fog of December 1952. He considers a rectangular area of 450 square miles covered by a stagnant mass of air 500 ft deep. The estimates and calculations of liquid and vaporous water contained in, lost from, and added to this mass, and the setting up of balances of smoke, sulphur, halogens, and oxides of carbon, as well as the toxicity caused, are well worth a close study, however much the numerical values may differ from the unfortunately unascertainable truth.

R. LESSING

PESTICIDES

Chemistry and Uses of Pesticides (*second edition*), *by E. R. de Ong. Pp. vii* + 334. *Reinhold Publishing Corporation, New York; Chapman and Hall Limited, London.* 1956. 70*s. net.*

The chemical industry now provides an almost bewildering range of toxic substances or 'pesticides' for those concerned with the prevention or eradication of insect, fungal, plant, and rodent pests. There has thus developed a need for authoritative books which explain the nature and uses of pesticides and their hazards: Dr de Ong has supplied one such book. In view of their dependence on climatic conditions, availability of suitably trained personnel, etc., control methods may differ greatly from one part of the world to another. It is not surprising, therefore, that Dr de Ong has largely confined his treatment of pesticide formulation and application to conditions obtaining in the United States. His book deals in turn with inorganic pesticides, petroleum products and pesticide solvents, fumigants, pesticides derived from plants, and the more recent synthetic organic compounds. A final chapter briefly treats the use of 'cold, heat, dehydration and radiation'. The direct use of beta and gamma irradiation by radioisotopes or high-voltage machines is, however, not discussed. An extensive appendix tabulates and classifies some 400 pesticides available in the United States. Final sections deal with pesticide residues permissible in food products in the United States, and with first aid for operators.

For a second edition there are a large number of minor errors: for example, methyl bromide and bromoethane are taken to be synonymous. The book will be useful to practical students of agriculture and to those concerned with the control of pests in a wide sense.

F. P. W. WINTERINGHAM

ESSENTIAL OILS

Die ätherischen Öle (Gildemeister-Hoffmann), *Vol. IV, edited by W. Treibs and K. Bournot. Pp. xxxii* + 720. *Akademie-Verlag, Berlin.* 1956. *DM.* 55 *net.*

This is part of the fourth edition of the well-known handbook originated by E. Gildemeister and F. Hoffmann. At present about 2400 plant species are known to contain essential oils (as compared with about 1370 in 1931 when the original was published). The increase in number, and developments in methods for extracting and characterizing essential oils, have caused the new edition to expand to seven large volumes. Volume IV describes the relatively few essential oils from cryptogams, and commences the discussion of the much more numerous essential oils associated with seed-bearing plants. Turpentine and other oils of the conifers are fully covered, together with the volatile oils of nearly forty dicotyledonous families. Among the latter are the technically important scented grass oils (palmarosa, lemongrass, citronella, etc.) and those of orris, ginger, sandalwood, star anise, nutmeg, etc.

The treatment is exhaustive, and the layout, typesetting, and indexes are excellent. The complete series will assuredly maintain the tradition of the original classical monographs.

T. P. HILDITCH

MOLYBDENUM

Metallurgy of the Rarer Metals, No. 5: Molybdenum, *by L. Northcott. Pp. xii* + 222. *Butterworths Scientific Publications, London; Academic Press Inc., New York.* 1956. 40*s. net.*

Molybdenum has hitherto been used mainly as a constituent of special ferrous alloys, with a minor application of the pure metal in the form of filaments for valves, etc. However, with the advent of new techniques for processing high melting-point metals the possibility of widening the scope of the application of molybdenum has become greater. This book is therefore most welcome in providing potential users with a background of information on the mechanical, physical, and chemical properties. The subject matter follows the general trend used in other volumes of this series. Chapters are included on extraction and refining of molybdenum, general physical and mechanical properties of the pure metal and its alloys, fabrication, arc-melting, and various methods of joining. The alloying characteristics of molybdenum are clearly summarized and include constitutional data on 52 binary, and various ternary, alloys. The oxidation of the pure metal and selected alloys is discussed together with present methods of affording protection. Valuable bibliographies are provided at the end of each chapter.

B. W. MOTT

Short notices of books

(These notices are descriptive rather than critical and are designed to give a general indication of the nature and scope of the books.)

The Condensed Chemical Dictionary (*fifth edition*), *by Arthur and Elizabeth Rose. Pp. xix* + 1200. *Reinhold Publishing Corporation, New York; Chapman and Hall Limited, London.* 1956. 100*s. net.*

While this is a valuable reference work for all chemists, it is especially so for those concerned with industry and commerce. It gives a wealth of information about the properties, derivation, uses and trade names of a wide range of commercially available chemicals; it should be noted that some information such as that on specification, containers, and shipping regulations relates specifically to American practice. This new edition is very substantially larger than the fourth edition of 1950, which has been completely revised and brought up to date.

The Historical Background of Chemistry, *by H. M. Leicester. Pp. viii* + 260. *John Wiley and Sons Inc., New York; Chapman and Hall Limited, London.* 1956. 48*s. net.*

This book deals comparatively little with the biographies of chemists, and places the main emphasis on the development and interrelation of chemical concepts. Although much of the book is devoted to the period before chemistry came to be regarded as a science in its own right, the last chapters deal with modern times, and include discussion of radioactivity and atomic structure and of biochemistry.

*p*H Measurements. Their Theory and Practice, *by Victor Gold. Pp.* 125. *Methuen and Company Limited, London; John Wiley and Sons Inc., New York.* 1956. 9*s.* 6*d. net.*

This addition to Methuen's well known series of monographs on chemical subjects describes the basic theory of *p*H and the principal methods of measuring it. It includes a chapter on the *p*H concept in relation to non-aqueous solvents. The book is written for the general scientific reader and assumes no detailed knowledge of physico-chemical theory.

Hydrogen Ions. Their Determination and Importance in Pure and Industrial Chemistry. *Vol.* 2 (*fourth edition*), *by Hubert T. S. Britton. Pp. xix* + 489. *Chapman and Hall Limited, London.* 1956. 75*s. net.*

This volume provides the advanced chemist with a detailed discussion of the role of hydrogen ions in chemistry and in a number of important industrial processes, such as tanning, sugar refining, water purification, and ore flotation. An important addition since the third edition of 1942 is a description of electrometric methods for the titration of acids and bases in non-aqueous media.

Paper Electrophoresis, *edited by G. E. W. Wolstenholme and Elaine Millar. Pp. xii* + 224. *J. and A. Churchill Limited, London.* 1956. 35*s. net.*

This is an account of a three-day symposium on paper electrophoresis arranged by the Ciba Foundation in London in July 1955. The symposium included both general papers—for example, on high-voltage techniques—and papers on special applications. Particular emphasis was laid throughout on identification of the factors responsible for differences between results obtained in different laboratories, so that reliable comparisons can be made.

Times and Places, *by the late Harold Peake and H. J. Fleure. Pp. xv* + 336. *Clarendon Press, Oxford; Cumberlege, London.* 1956. 42*s. net.*

This is the tenth and last volume of the 'Corridors of Time' series, which is designed to give the general reader an account of human evolution from the beginning until the civilizations of classical times in the Mediterranean. About one-fifth of the book deals with comparatively recent work on man in the Old Stone Age. The second part deals with the origin and spread of methods of food production.

Physiologie de l'insecte (*second edition*), *by Remy Chauvin. Pp.* 917. *Institut National de la Recherche Agronomique, Paris.* 1956. *Fcs* 3500 *net.*

In preparing the second edition the author has completely revised the text of the first and extended it by some 300 pages: the bibliography now comprises almost 2800 references. In the revision particular attention has been given to the chapters on the integument, moulting, diapause, and sexual hormones.

Automation in Theory and Practice, *by E. M. Hugh-Jones. Pp. ix* + 140. *Basil Blackwell, Oxford.* 1956. 12*s.* 6*d. net.*

This comprises a series of lectures on automation given in Oxford in 1955. The subject is considered from many points of view—including that of the scientist, engineer, trade unionist, and economist. The book concludes with a three-page bibliography.

Grandes découvertes du xx^{e} siècle, *edited by Louis Leprince-Ringuet.* Pp. 503. *Librairie Larousse, Paris.* 1956. *Fcs* 2705 *net.*

This book, in the characteristic Larousse style, attempts a comprehensive survey of modern science written at the level of the general reader. It is well illustrated and covers a remarkably wide field, but the emphasis is on the physical rather than the biological sciences.

Lecture Notes on the Use of the Microscope (*second edition*), *by R. Barer. Pp. v* + 76. *Blackwell Scientific Publications, Oxford.* 1956. 7*s.* 6*d. net.*

This is a basic elementary text for all students who have to use a microscope. The emphasis is on practical instruction, but there is a short section on theory.

Spot Tests in Organic Analysis (*fifth edition*), *by Fritz Feigl. Translated by Ralph Oesper. Pp. xx* + 616. *Elsevier Publishing Company, Amsterdam; Cleaver-Hume Press Limited, London.* 1956. 55*s. net.*

This fifth edition of a very well known work takes note of the considerable progress made by Professor Feigl and other workers in the field since the last edition appeared only three years ago. More than eighty new tests, some not previously published, are described, and there is a new section on the identification of substances of medicinal interest.

Notes on contributors

SIR CHRISTOPHER HINTON,
K.B.E., M.A., D.Eng., D.Sc.(Eng.), F.R.S.,

Was born in 1901 at Tisbury, Wiltshire, and was educated at Chippenham Grammar School. After serving an apprenticeship with the Great Western Railway at Swindon, he was awarded the William Henry Allen Prize and went to Trinity College, Cambridge. In 1926 he joined the Alkali Division of Imperial Chemical Industries Limited at Northwich, where he remained until 1940, becoming Chief Engineer in 1931. From 1940 to 1946 he was on loan to the Ministry of Supply, becoming Deputy Director General of Filling Factories. On the formation of the Division of Atomic Energy in 1946 he was appointed Deputy Controller (Production), and on the formation of the Atomic Energy Authority became a member of the Board and Managing Director of the Industrial Group.

C. T. INGOLD,
D.Sc.,

Was born in Dublin in 1905 and was educated at Queen's University, Belfast. In 1930 he became lecturer in Botany at the University of Reading and in 1937 lecturer-in-charge in the Department of Botany, University College, Leicester, 1937–44. Since 1944 he has been Professor of Botany in the University of London (Birkbeck College). He was President of the British Mycological Society in 1953. He has published papers on aquatic fungi (particularly aquatic Hypnomycetes) and on spore dispersal. He is the author of 'Spore Discharge in Land Plants' (1939) and 'Dispersal in Fungi' (1953).

J. P. HUDSON,
M.B.E., G.M., M.Sc., Ph.D., N.D.H.,

Was born in Derbyshire in 1910 and took a degree in horticulture in the (then) University College of Nottingham. He spent six years in the horticultural industry and as Assistant Horticultural Officer in East Sussex, and then served throughout the last war in the Royal Engineers as a bomb disposal officer. After demobilization, he spent three years as horticulturist to the New Zealand Government, and then returned to the University of Nottingham as Lecturer in Horticulture. In 1950 he was appointed Head of the Department of Horticulture at the School of Agriculture, Sutton Bonington.

W. G. OVEREND,
D.Sc., Ph.D., F.R.I.C.,

Was born in 1921 and was educated at the Priory School, Shrewsbury, and the University of Birmingham. In 1946 he became Assistant Lecturer in chemistry in University College, Nottingham, and in 1949 was appointed Lecturer in chemistry in the University of Birmingham. Since 1955 he has been Reader in organic chemistry at Birkbeck College, University of London. His research has been concerned mainly with the chemistry of carbohydrates and nucleic acids.

A. R. PEACOCKE,
M.A., B.Sc., D.Phil.,

Was born in 1924 and was educated at Watford Grammar School and Exeter College, Oxford. After carrying out research at Oxford on the kinetics of bacterial growth, he joined the chemistry department of the University of Birmingham in 1948, first as an Assistant Lecturer and then as a Lecturer. During 1951–52 he held a Rockefeller Fellowship at the Virus Laboratory, University of California, and at the University of Wisconsin. Recently he was appointed Senior Lecturer in Biochemistry in the Department of Microbiology, University of Birmingham. His research work has mainly been concerned with the physical chemistry of nucleic acids.

R. MARKHAM,
M.A., Ph.D., F.R.S.,

Was born in 1916 and was educated at St Paul's School and Christ's College, Cambridge. After studying biochemistry he was appointed assistant to the Director of the Plant Virus Research Station, Cambridge, where he was engaged in the diagnosis of plant virus diseases and in the investigation of viruses by physical methods. For many years he has been interested in the chemistry of viruses, and particularly in the nucleic acids, which seem to play a very important part in virus multiplication. His recent work has been mainly concerned with structural problems of the nucleic acids and their degradation products. He is an editor of the *Biochemical Journal.*

W. O. JAMES,
M.A., D.Phil., F.R.S.,

Was born in London in 1900 and was educated at Tottenham Grammar School and the Universities of Reading and Cambridge. Worked first on the potassium nutrition of plants on field plots at Rothamsted. Is Reader in botany in the University of Oxford, and since 1927 has led a school of teaching and research in plant physiology, especially concerned with nutrition and respiration. Director of the Oxford Medicinal Plants Scheme during the war and after, dealing with the production of drug plants in Britain and with the study of alkaloid metabolism in the Solanaceae. An editor of the 'New Phytologist'. Has published 'The Biology of Flowers' (with A. R. Clapham), 'Plant Respiration', some well known textbooks, and numerous papers in several branches of botany.